AD-A145 739 FORECASTING WATER USE ON FIXED ARMY INSTALLATIONS WITHIN THE CONTIGUOUS UNITED STATES(U) ARMY MILITARY PERSONNEL CENTER ALEXANDRIA VA J F LANGOWSKI 22 JUN 84 1/3

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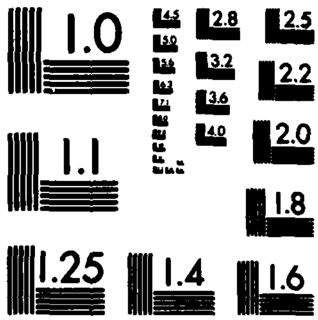


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| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle) FORECASTING WATER USE ON FIXED ARMY INSTALLATIONS WITHIN THE CONTIGUOUS UNITED STATES | | 5. TYPE OF REPORT & PERIOD COVERED Final Report - 22 Jun 84 |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s) LTC John F. Langowski, Jr. | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS Student, HQDA, MILPERCEN (DAPC-OPA-E) 200 Stovall Street Alexandria, Virginia 22332 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS HQDA, MILPERCEN, ATTN: DAPC-OPA-E 200 Stovall Street Alexandria, Virginia 22332 | | 12. REPORT DATE 22 June 1984 |
| | | 13. NUMBER OF PAGES 181 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | | 15. SECURITY CLASS. (of this report) Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DTIC ELECTE SEP 25 1984 S D B

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

A dissertation submitted to the Department of Geography in the Graduate School, Southern Illinois University in partial fulfillment of the requirements for the Doctor of Philosophy degree.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Forecasting, Water Conservation, Installation Water Use, Water Management, Installation Utility Management, Statistical Analysis, Multiple Regression, Water Contingency Planning, Mobilization Planning.

This dissertation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)


This study ascertains the status of selected water planning activities on Army installations and explores the possibility of integrating available data, measurement techniques and water use forecasting concepts into an improved water requirement model for operative consideration by Army installation planners and managers. The study focused on two questions. These were:

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1) What is the nature and type of water planning being practiced by installation water utility managers?


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2) How can procedures for estimating installation water requirements be improved to provide a basis for other essential water planning activities?

(cont)

The first study question was concerned with gathering and analyzing information that would provide a broad perspective on what installation planners are doing to prepare for potential water supply problems expected to occur by the turn of this century. ~~An~~ analysis of average costs for water utility operations, maintenance and repair established that combined average costs are increasing significantly in real dollars and are likely to continue to rise, particularly on posts where aging system components will need replacement. Improved planning procedures are needed to identify beneficial courses of action to curb these costs. Existing procedures and planning practices of 86 installations were assessed and the results indicate that better planning guidelines are needed in three areas: water requirement forecasting, water shortage contingency planning and procedural assessment of potential water conservation measures. The status of current water planning efforts are analyzed and presented relevant to mission orientation, sources of water and other installation-related water use characteristics.

The second research question focused on the formulation of an improved planning method to estimate installation peacetime water requirements. ~~An~~ analysis of the total building gross floor area of all structures on an Army post determined that three statistically significant sectors of water use composed of groups of specific building categories can be identified: a community service and support sector, a military activity sector, and a research and utility support sector. When empirical data representing these sectors were tested within a conceptualized linear additive model, the result was to explain 87 percent of the variance of average daily water use, compared to 56 percent employing current Army per capita procedures.

# FORECASTING WATER USE ON FIXED ARMY INSTALLATIONS WITHIN THE CONTIGUOUS UNITED STATES

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22 June 1984

Approved for public release; distribution unlimited.

A dissertation submitted to the
Department of Geography in the Graduate School
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in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

SIU

# Dissertation Approval

**The Graduate School**
**Southern Illinois**
**University at Carbondale**

June 22, 19 84

I hereby recommend that the dissertation prepared under my supervision by

John F. Langowski

**Entitled**

Forecasting Water Use on Fixed Army Installations
Within the Contiguous United States

be accepted in partial fulfillment of the requirements for the

**DOCTOR OF PHILOSOPHY degree.**

Duane D. Baumann
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Recommendation concurred in

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John Bandy
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Benedykt Dziegielewski
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**Committee for the Final Examination**

## ACKNOWLEDGEMENTS

This research effort could not have been completed without the cooperation and assistance of numerous other individuals and agencies who contributed their time, service and funds during the accomplishment of this study. I would like to thank the U.S. Army Construction Engineering Research Laboratory for their grant of financial assistance of my doctoral program and the continuous assistance to me in acquiring the military data base and related documentation essential to the conduct of this study.

The installation visits and mail survey would not have been possible without the permission of the Deputy Director for Facilities Engineering and Housing, Office of the Chief of Engineers and the Major Command Engineers. I am also grateful to the many installation planners and managers who provided me with their valuable time and professional insights during the site visits and in response to the survey. Their cooperation and interest was always apparent and I am indebted to them for their support.

I wish to express a special gratitude to Professor Duane Baumann, my advisor, who encouraged and guided me throughout my development. My thesis committee, Dr. David Arey, Dr. Benedykt Dziegielewski, and Dr. Stanley Lieber of Southern Illinois University, Dr. John Boland of the Johns Hopkins University and Dr. John Bandy of the U.S. Army Construction Engineering Laboratory, all provided suggestions and

criticism which promoted my intellectual growth. Special acknowledgement must be given to Dr. Dziegielewski, who always shared his time, knowledge and scientific reasoning to mold my advancement.

The completion of this manuscript would not have been possible without Barbara Pearson who went beyond the proverbial call of duty to type the earlier and final versions of the dissertation. I am very thankful for her willingness to make unceasing changes with a smile.

Finally, I want to especially thank my wife, Joan, who has been my constant source of strength throughout the stress of my doctoral program.

## DEDICATION

This dissertation is dedicated to my father, John Sr. and to my mother, Ann, who always had high hopes for me.

## DISCLAIMER

Opinions, conclusions and recommendations expressed or implied within are solely those of the author and do not necessarily represent the views of the Department of the Army or any other government agency.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

CHAPTER | Page

TABLE OF CONTENTS (Continued)

## LIST OF TABLES

LIST OF TABLES (Continued)

## LIST OF FIGURES

## CHAPTER I

## WATER RESOURCE PLANNING ON ARMY INSTALLATIONS WITHIN THE CONTIGUOUS UNITED STATES

### Introduction

Planning for future water requirements on U.S. Army installations has recently received new emphasis, stimulated by national assessments of water resources availability, competition for its myriad of uses and increasing costs of development, treatment and distribution. A brief overview of the findings of these assessments provides important reasons for Army water utility planners and installations managers to review current planning guidelines and the methods now on-hand for estimating water needs to service soldiers, their families and civilians who reside or work on Army posts within the contiguous United States. Municipal and industrial water supply and demand management problems facing the nation's water utilities by the year 2000 are likely to have an impact on the operation and maintenance of water service and water systems on Army installations. Because these impacts can adversely affect mission accomplishment and the quality of life of soldiers and family inhabitants, recognition must be given to these problems and the need to sharpen planning tools that facilitate the identification of courses of action to improve the range of choice for Army decision-makers.

In general, historical installation water service planning has

focused on engineering design to determine the appropriate size of initial system configurations or the extent to which system components should be expaneded when existing capacities or capabilities were over-tasked. Army technical manuals which provide water supply planning guidance to installation facility engineers have not been substantially revised in approximately 30 years. Since 1979, however, these manuals have been undergoing review and it is essential that modifications incorporate improved water supply and demand management planning procedures. Such procedures should be commensurate with approved and proven techniques that can prevent premature investment or hasten overdue expenditures of Defense dollars in water utility expansion.

Planning for installation water service is a different challenge today for Army water utility managers than in the past. New reservoir sites are scarce and groundwater resources have been fully exploited in many areas. Production costs related to water service are being pressured upward due to higher energy costs and costs for water treatment technologies to comply with mandated water quality considerations. These problems are new and complex and require installation water planners to review goals and methodologies and modify management practices to avoid the occurrence or minimize the adverse impact of a water shortage. Therefore, the focus of this research will address two major questions: 1) What is the nature and type of water planning being practiced by installation water utility managers? 2) How can procedures for estimating installation water requirements be improved to provide a basis for other essential water planning activities?

This chapter establishes the rationale for this research and the

understanding of how these challenges bear upon Army installations. It begins with a capsule summary of recent pertinent national water resource studies and related federal documents. Four study objectives are stated prior to concluding with a brief description of the organization of this study.

## The Second National Water Assessment

The Water Resources Council's Second National Water Assessment (1978) examined the nation's water supply situation as of 1975. It identified that water shortages would increase locally or regionally in areas where there are usage conflicts, poor distribution of supplies, ground water mining and quality degradation and surface water pollution. These problems are expected to become magnified and worsened by the ever-increasing consumptive withdrawal of fresh-water through the year 2000. The financial burdens accompanying these problems are also alarming and suggest that as many as 20 percent of all urban water systems will be unable to finance capital investments for water systems rehabilitation, distribution expansion, improved water quality and new source development. The Subcommittee on Urban Water Supply of the President's Intergovernmental Water Policy Task Force (1980) has further emphasized that approximately $15 billion is being spent annually by the Nation's water utilities on operation and maintenance costs of existing water system facilities. Cumulative capital expenditures may reach as high as $110 billion by the year 2000. Collectively, these factors signal the need for a concomitant rededication of planning effort to

confront and reduce the adverse impacts of these projections. Water resource managers, particularly directors of municipal water utilities, regardless of size, location or institutional characteristics, cannot be excused from seeking to evaluate and find solutions to improve their present posture and future outlook in light of this recent national assessment.

Department of Defense water facility managers at fixed installations in the United States are not immune from facing these water planning challenges. Water shortages have taken place and may happen again on military installations, especially when they are located in regions where usage conflicts may become prevalent.

## Impact on Department of Defense Military Installations

A 1979 study conducted by the Research Directorate of the National Defense University (NDU) concluded that the problems related to water resources recognized in the Second National Assessment will have an adverse impact on Department of Defense military installations in the United States (Schwartz, 1979). Schwartz obtained the baseline data on water and related land resources from the Second National Assessment and examined the applicable data for each military installation in the primary base structure of the Army, Air Force, Navy and Marine Corps. He found that 91.7 percent of the 1,114 identified installations are located in hydrologic areas having problems with water and related land resources. Two-thirds of these installations are sited within Standard Metropolitan Statistical Areas where water use is highly competitive and

potentially intensified by the needs of military communities. He concluded that water resource problems will have an adverse impact on the Department of Defense (DOD) in at least three areas:

(1) Increased costs. The costs for useable water will be driven upward by the expense to correct water supply and quality problems and will be reflected in both the costs for purchased water as well as installation-produced water.

(2) Reduced use of water. Past litigation to ensure unrestrained use of water on military installations may be overshadowed by a mandated DOD program to reduce water consumption, like other mandated programs in energy, pollution and solid waste. Nearby local communities confronting water shortages may pressure installation commanders to reduce water usage. A flexible water conservation policy is a principal method for mitigating this problem, but requires incentives to motivate evaluation, adoption and implementation. A staff study by the U.S. Government Accounting Office (1979, p. 32) discussed several opportunities for encouraging and implementing water conservation programs, particularly by federal agencies which construct and operate public buildings and military and civilian housing. Also, the recently revised Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (U.S. Water Resources Council, 1983) specifies that conservation measures are to be included in the evaluation of national economic development benefits of municipal and industrial water supply plans.

(3) Base closures and mission alignment. In some areas, water supply, treatment, storage or distribution may be the most significant

determining factor in decisions to close or expand installations.

In order to adjust and improve these operational methods, however, each military service must inevitably be able to estimate water usage, disaggregated into reasonable sectors of similar usages. For example, numerous studies of civilian communities have clearly shown marked differences among residential, commercial, industrial and public/institutional water requirements. Moreover, the evaluation and selection of conservation measures, an accepted form of water demand management, depends fundamentally on the availability of a disaggregated water use forecast (Baumann, 1980).

## General Implications on Department of Army Installations

The National Defense University (NDU) study determined that 93 percent of the Army's installations are in hydrologic areas with recurring water problems of insufficient quantity and decreasing quality. A major impact will be in Operations and Maintenance Appropriations because water service will cost more to produce on post. Adjacent municipalities, which provide water to installations, are expected to increase prices to recover from capital expenditures. Pressures will likely increase to pass on these costs to housing occupants and other post customers. Expansion capabilities will indeed be affected by what could be the limiting factor to accomplishing a mission requirement to add troop units to the base strength of an installation - inadequate water service. The study recognized that water conservation is a primary method for alleviating a shortage problem. However, there have been few

incentives to conserve and water conservation is suspected of receiving little emphasis at the installation level. The study recommended the establishment of a Department of Defense water resource conservation policy, broad enough to allow Army installation officials to establish their own goals based on procedures and guidelines for assessing potentially beneficial conservation measures.

The United States Army, with installations (also referred to as posts or stations) based world-wide, has real property ownership and responsibility for the composite operation and maintenance of 11,700 miles of water lines servicing more than one billion square feet of building area on an acreage equivalent to the combined areas of Massachusetts, Connecticut and Rhode Island. The total cost for Army world-wide water service operation reported by the Office of the Chief of Engineers (1982a, p. 42) for Fiscal Year (FY) 1981 was $62.5 million, up 22 and 31 percent in current dollars respectively, when compared to expenditures in FY 1979 and FY 1980. The average daily service population, on the other hand, has remained comparatively stable at 2 million people during this same time period. Installations within the United States alone account for nearly 80 percent of the 125 billion gallons of water produced for approximately 100 government operated Army installations in FY 1981. Clearly, the Corps' military role in water resource management is a major responsibility, reflected by these costs and volume of use. This function warrants its share of planning and management emphasis even without consideration of the requirements to prepare contingencies to supply water to support potential military operations world-wide.

Within the Army's military structure of command and control responsibilities, the Corps of Engineers is charged with providing technical guidance to and the monitoring of Army installation water utilities. The Corps is readily recognized as a principal agency involved in water resource project planning and implementation. The mission of the Corps has been extended and expanded by Congress since the early 19th Century and today includes navigation and flood control projects and related works associated with these major taskings (Office of the Chief of Engineers, 1981b). Water resource management is an implied, if not direct function of the Civil Works program of the Corps, but it is not often identified with the concurrent military mission of providing water service to nearly 2 million soldiers, family members and civilian employees residing or working on Army installations throughout the world.

The Corps of Engineers began research studies in 1978 to define conservation as a component of water policy and integrate water conservation planning into its civil works water supply program. The Corps has developed a Procedures Manual for evaluating water conservation as a part of municipal and industrial water supply planning and it has been disseminated to division and district field planners for execution in applicable civil works projects (Baumann, et al, 1980). The Corps appears to be committed to continuing this research, with an emphasis on practical application.

It does not appear, however, that a parallel framework exists for evaluating potential water conservation measures to support the planning needs of water supply activities on Army installations. There are

long-term military, economic and social benefits that can be realized by adjusting and incorporating the research that has been accomplished by the Corps into a water conservation and drought management program specifically adaptable to Army installations.

## Army Installation Water Supply Planning Guidance: What is Needed

The Corps' Institute for Water Resources contends that the evaluation of water conservation measures must be based upon and facilitated by a disaggregated forecast of water requirements that predicts the unrestricted use of water (Crews and Baumann, 1984). Baumann, et al. (1980) clearly indicate that estimating the effectiveness of a water conservation measure is a function of its effects on specific types of sectoral water use. To measure beneficial reductions in water uses and losses, the unrestricted quantity of water used by appropriate sectors must be known in advance. Unless a reasonable estimate can be made of current water usage in family housing and bachelor soldier quarters, for example, prediction of the effects of installing low-flow shower heads in these specific buildings cannot be ascertained. Evaluation of this potential water conservation measure depends upon knowing in advance the expected effectiveness within the "residential" sector in terms of water reduction quantities and customer acceptability. Herein lies the major dilemma of water conservation planning for military installations. Water use by sectors corresponding to the conventional classification of residential, commercial and industrial water use is currently unassessed and is not incorporated into practiced methods for estimating water needs

at Army posts.

Water requirements for an installation can be generally differentiated between peacetime needs and water service quantities to support expansion and mobilization in the event of a national emergency. In order to determine the water service expansion capability of an installation, upon which mission assignments and troop alignments are based, it is clearly essential that facility planners know the water usage profile and patterns exhibited in a non-mobilization setting.

Historical average daily water usage on Army installations has been computed based on an effective population, adjusted by a sizing capacity factor, and multiplied by a peacetime daily per capita usage of 150 gallons. There is no discrimination among categories of water usages and supposedly very limited meter data to permit differentiation. The Army's Construction Engineering Research Laboratory (CERL) conducted a study to determine proportions of water consumed by major category at Fort Bliss, Texas, Fort Bragg, North Carolina, Fort Lewis, Washington and Fort Carson, Colorado (Bandy and Scholze, 1982). They concluded that the largest users of water on these fixed installations were troop and family housing and landscape irrigation. Industrial water use, especially tactical vehicle washing, also represented a major component of water use. The four selected installations were expected to differ in certain sectoral water usages and the findings verified this hypothesis, but without an explicit comparison to reveal reasons for differences or similarities. An ongoing study is being conducted by CERL to continue to address this problem of measuring use across user sectors by installing meters at selected points in the distribution system at Fort Bragg. This

project may provide representative data on selected water user activities for comparison with similar data from other installations.

Underlying this approach is the general assumption that water usage activities on an Army installation can be aligned with common sectors describing water use patterns in civilian communities (Table 1). It appears reasonable to accept this assumption as a starting point for assigning water use "activities" into a convenient classification scheme; however, there are differences in the magnitude and scope of water use within these categories when compared to counterpart civilian sectors. Commercial activities are collectively known as the post exchange and are controlled by the Army and Air Force Exchange System (AAFES). At most installations, the post exchange consists of a general retail store, a movie theater, a tailor shop, a barber shop, shoe repair shop and cafeteria. Other merchant enterprises are operated by AAFES concession and generated profits are used for the support of soldier recreational and athletic programs. Generally, there is no need for commercial competition and all commercial buildings on a military post are sized to support an expected population base. Moreover, every building is operated and maintained by the Installation Engineer and real property is government owned. Community service activities such as churches, schools, arts and crafts centers and other indoor recreation facilities are sized in the same way. In fact, military churches and chapels support multi-denominations of religions under the same roof, but with well-planned schedules that prevent conflict among the various clergy and congregations.

Ideally, metered data or billing information would provide the

TABLE 1

TYPICAL ACTIVITIES REQUIRING WATER ON ARMY FIXED INSTALLATIONS

| Residential | Commercial |
| --- | --- |
| Family housing | Main/branch post exchange |
| Bachelor soldier quarters | Commissary |
| Guest/visitor quarters | Bank |
| Temporary/transient housing | Post office |
| Sprinkling/landscape irrigation | Gas station(s) |
| | Laundromats |
| | Car wash |
| | Cafeterias/restaurants |
| | Main clubs and annexes |
| **Industrial** | **Public/Institutional** |
| Vehicle and aircraft wash facilities | Offices and conference areas |
| Industrial laundry and dry cleaning | Classroom and instructional facilities |
| Automotive, tracked and engineering maintenance facilities | Command-level headquarters |
| Boilers and steam generation | Communications facilities |
| Laboratories | Landscape irrigation |
| Metal cleaning, plating and finishing | Air terminal operations |
| Cooling towers and wet scrubbers | Shipping and receiving |
| | Fire water |

data base for facility managers to accurately assess existing water use patterns and measure water usage quantities by sector. The existence of this type of data base is questionable at best because water is not priced and rarely metered on Army installations. This condition has the effect of currently limiting the method of forecasting future water service to a per capita approach, based upon average daily water delivery. Moreover, this approach and the accompanying guidelines that prescribe procedures for estimating average daily water demand are inadequate and an improved method is needed to improve water supply planning at Army installations.

Finally, the NDU study emphasized the need to define the impacts of usage conflicts at individual installations and determine appropriate courses of action. To date, however, there is a void of information pertinent to these issues and their actual relevancy to Army installations has not been established. To some degree, they may be construed as conjectural unless supported by empirical evidence. The existing data base for the Army contains some valuable cross-sectional water service information for individual installations in the United States; however, these data have not been comprehensively analyzed to provide a meaningful perspective of the nature and character of installation water service. This existing information base could provide an insight particularly regarding sources of water supply and trends in operation and maintenance unit costs. Other issues, such as the extent of water conservation practices, the presence of water use forecasts, and the availability of documented contingency plans for water shortage events cannot be assessed without further data collection.

## Study Purpose

This study was undertaken primarily to develop an improved planning tool for installation water managers to use in predicting average daily water requirements. A preliminary analysis of existing procedures indicated serious problems in forecasts which are based on computational approximations of per capita water usage. This approach has been used in the past throughout the water industry but it provides, at best, a rough estimate of water use and excludes consideration of other factors which affect water use, such as economic indicators, social preferences, weather-related variables and other differences in categorical usage. Analytical models which include these considerations have been shown in the literature to improve forecasts and thus prevent unnecessary or belated investment decisions in water supply planning. The model developed in this study exhibits this preferred approach to forecasting.

It is still not certain whether conclusions regarding Army water supply planning put forth in the NDU assessment can be verified or rejected without obtaining information that would shed light on recent operation and maintenance costs, installation water conservation practices and installation contingency preparedness to cope with an emergency water shortage situation. This kind of data could be used to ascertain the legitimacy of the conclusions of the NDU report and provide further incentives to improve installation water planning procedures. The procedures implied here are not only water requirement forecasting, but also water conservation evaluation and water shortage contingency planning. Therefore, an adjunct purpose of this study is to obtain

information gathered from existing data bases or by generating new data and broadening the information pertinent to these issues. Very little aggregated information is currently on hand and Army water resource managers are needing information from individual installations to determine the status of installation water supply planning. An inventory of water supply planning activities is clearly warranted.

Although it is meritorious to want to improve planning tools, there needs to be a solid justification for changing from current practices. To improve denotes explicitly the intent to make better and it is necessary to demonstrate that on-hand guidelines are not performing well enough to continue as standing operating procedures. It is therefore important to examine these current water planning methods and practices and evaluate their efficacy. If faults are found which cannot be easily corrected, and if continued use can lead to unsound investment decisions, then old ways must be urgently replaced by better techniques.

## Dissertation Objectives

The specific objectives of this study are four-fold:

1. To identify and report on available information and empirical data which supports or rejects the conclusions of the NDU study regarding increasing water-related operation and maintenance costs and inadequate water supply planning emphasis on Army installations in the 48 contiguous United States;

2. To evaluate current guidelines and procedures for estimating average daily water demand prescribed by Army technical manuals and

demonstrate predictive ability, using empirical installation data;

3. To discern distinct sectors of installation water use as a function of allocated building area gross square footage; and,

4. To test and evaluate a conceptualized linear additive model that relates these sectors to average daily water use and interpret the regression results.

In order to accomplish these objectives, it was necessary to conduct a literature search of both military and civilian documents related to water supply planning and forecasting. CERL library assistance facilitated the military document review and furnished the data base of facility engineering annual operations and maintenance activities. Visits were made during January, 1984 to thirteen installations located from Fort Hauchuca, Arizona to Walter Reed Army Medical Center in Washington, D.C. where additional information was obtained during discussions with more than 60 installation utility managers, water treatment plant supervisors and master planners. Additionally, a mail survey was undertaken from January, 1984 through March, 1984 in which 93 installations were contacted and 86 responded (92%) to questions relevant to the NDI assessment. The details of each of these activities are given in the following chapter, together with the methods of data analysis.

## Organization of the Report

A description of the sources of data used in this study is presented in Chapter II. The methods of data collection and statistical analysis used at various stages in the evolution of this study are identified.

Chapter III provides a description of the organizational structure for water utility planning and related recent planning activities at Army installations. It will be shown that the conclusions of the NID report in some ways are partially verified thus providing solid signals for intensifying installation water supply planning efforts. Because planning for future water needs is critically dependent on the accuracy of water requirement forecasting, it is appropriate to review in Chapter IV the forecasting methods and techniques available to the water industry in general and evaluate the procedures being used now in the Army for water service estimation and future prediction.

The focus on water service forecasting continues into Chapter V. It is hypothesized that average daily water use can be explained by a statistical relationship with building area categories grouped into new composite variables that offer a sectoral representation of water use patterns on an installation. This hypothesis is systematically tested within the construct of a linear additive model using relevant empirical data for 90 installations. The results are interpreted and contrasted graphically with the predictive capability of existing procedures. Chapter VI summarizes the major findings of this study and concludes with recommendations for further research.

# CHAPTER II

# SOURCES OF DATA AND RESEARCH DESIGN

The extent and depth of data acquisition is made explicit in this chapter and the statistical procedures employed to analyze the obtained data are identified. It is important to describe and discuss the sources of data that were assessed for relevancy to the study in order to note what type of information is currently on-hand within the military facility engineering structure. There are differences in data management methods and operational policies between Army installations and counterpart civilian communities which will be shown herein. Because of these differences, it was fundamental to this research to gain an understanding of water utility operation and water requirement forecasting in both arenas in order to discern strong and weak points in current installation water service planning.

## Water Service for Army Installations and Civilian Communities: A Comparison

Army installations in the contiguous United States resemble small civilian communities, ranging in populations of 100 to 70,000 people. There is some similarity in the water utility management infrastructure in that the typical civilian community Director of Public Works, assisted

by a planning and engineering staff and water treatment plant personnel, is mirrored by the Director of Engineering and Housing (DEH) and a commensurate support workforce on an Army installation. In this example, both are under the domain of government ownership. There are no privately owned water utilities located within a military installation, although water may be purchased from a nearby public or private utility to serve installation needs. Water for either type of community may be obtained directly from surface or ground water sources or purchased from wholesalers. Operation and maintenance costs are parallel between both entities; however, these costs as well as capital expenditures for military installations are appropriated and programmed as part of the Department of Defense budget. Water quality standards, promulgated by federal or state regulatory agencies, are adhered to by both civilian and military communities. Also, it has already been suggested that water-using activities on an Army installation may be aligned with commonly recognized sectors of water use: residential, commercial, industrial and institutional water use. These likenesses between Army installations and civilian communities imply that advancement in water planning methods, particularly water requirement forecasting techniques, are equally applicable and appropriate for consideration by both parties. This last point was used as an initial assumption in gathering information relevant to this study and accordingly, stimulated a literature review to determine the scope, content and results of studies related to water demand forecasting.

Although there are strong similarities, there are special considerations that must be given to the nature of water use which

indicate some difference when compared to sister civilian communities. Scholze, et al, (1982) have indicated that:

(1) Total service population fluctuates daily because of large numbers of civilian employees who reside off-post and commute daily to their jobs on the post. The number of consumers also varies with soldier maneuvers and training exercises conducted within and beyond installation boundaries. The impact can range from hundreds to thousands of Reserve or Army National Guard soldiers arriving for temporary duty during certain periods of the year, causing large surges in normal water service; on the other hand, tenant troop units may deploy for training at sites beyond the installation, causing corresponding reductions in total water quantities;

(2) Army personnel pay a fixed amount for unlimited quantities of water through forfeiture of their quarters allowance and are not subject to rate structures. They do not pay directly for the water they use and, therefore, meters with limited exception, have not been needed;

(3) Activities unique to the Army, such as tactical vehicle and aircraft washing and maintenance, affect installation water service and quantity requirements; and

(4) Army personnel must follow command orders and instructions, implying quick enforcement of directives implementing water conservation measures.

In addition to Scholze's points, there are additional qualifiers that may relate to water service or water utility record management:

(5) Installations are characterized by their military missions: soldier schools and major training centers, logistical production and supply depots, medical centers or research development and testing sites. Although some installations are dedicated primarily to one of these missions in most cases, there are activities that represent some aspect of all of these missions with one or two dominating missions.

(6) Installation real property (all buildings and acreage) is Army owned, operated and maintained by the Director of Engineering and Housing (DEH) on behalf of the Installation Commander. Procedurally, the DEH recommends to the Commander actions for improving the efficiency and capability of support on a continuing basis. A commander's decision to implement the recommendation, such as water conservation measures, is communicated as a directive and if it involves water reduction plumbing fixtures or educational programs, the DEH will comply throughout the installation. The reciprocal also holds in that a commander's decision <u>not</u> to conserve, such as limit irrigation of common areas such as parade and athletic fields and other large grassed areas, is also carried out.

(7) Installations are designed to support the activities related to their military mission: various training areas, vehicle and aircraft park and maintenance complexes, family and soldier housing, community buildings and other building categories are surrogated representatives of both the population size and mission activities of the installation. As

such, allocated buildings, their sizes and numbers symbolize places where people use water and how water is used.

(8) Utility conservation within the Army is focused on a reduction of energy consumption and includes water conservation as a means to achieving energy reduction goals. For example, low-flow shower heads have been installed on some posts with the intent of reducing energy costs related to boilers or water heaters. There is no water conservation policy per se.

(9) Periodic water service operation and maintenance reports are submitted from the installation level through the Major Command (MACOM) having jurisdictional authority. In turn, the staff engineer at the MACOM reviews and forwards consolidated reports to the Directorate of Military Programs, Office of the Chief of Engineers. The feeder reports are standardized and well-defined in terms of what is to be reported and how it is to be computed using standard units of measure. Annually, these reports are consolidated, published and distributed Army-wide to provide commanders and staff officers with an analysis of the Army's real property maintenance activities for the preceding fiscal year (ending September 30). The annual report which is commonly referred to as the Redbook, is a valuable source of raw data for an analysis of the major facets of facility operation and maintenance. The Directorate of Military Programs also issues technical guidance for installation water utility management in the form of periodic manuals and bulletins.

This last consideration suggests the source of data for water service activities on Army posts. Published copies of these annual reports were obtained and reviewed for application to the objectives of this study. This data base and other potential sources of information are discussed in the next section of this chapter.

## Data Base and Data Collection Procedures

### Published Sources of Data

Each year, through Fiscal Year (FY) 1981, the Directorate of Military Programs, Office of the Chief of Engineers, has prepared an Annual Summary of Operations report to provide a general analysis of all of the major facets of maintenance and operation of Army-wide facilities. The Redbook, as it is cited, is divided into seven parts which report costs and operating data for major component activities, such as buildings and grounds, utility operation and fire prevention protection. Of interest to this study is Part VII which presents specific water service and system data by installation. The data and related statistics are compiled from Major Command technical data reports, DA Form 2788 series (AR 420-16) and follows the Army management structure classification and reporting requirements (AR 37-100-XX, where XX represents the last two digits of the fiscal year). The Army is in a transitional period between manual preparation of the technical data reports and an automated interactive user oriented management data base which will be available by the end of FY 1984. Consequently, Redbooks

for FY 1982 and 1983 have not been published. The Redbook for FY 1981, therefore, represents the most recent publication.

A total of seven years of selected data for Fiscal Years 1975 through 1981 was extracted for this study. Prior to 1975, report formats and activity codes differed in some respects and operational and maintenance data was not typical due to installation adjustments in troop support caused by the end of the Vietnam Conflict. This data base served as the primary source of information for the water use model developed in Chapter V.

Within the Fiscal Year 1981 Redbook, 90 separate installations, located within the contiguous United States, are reported and they are listed in Table 2, categorized by Major Command (MACOM). These 90 installations represent the entire population of active Army owned and operated fixed posts located within the study area, managed by a Facility Engineer Activity and subject to the requirements for individually reporting annual facilities engineering technical data (DA Form 2788-R). The term "fixed" is used here to mean permanently established installations where water service operation and water system maintenance is managed by a facility engineer under the delegated authority of the Installation Commander. This set of installations constitute the target for study in this dissertation.

Water utility data for each installation is entered in the Redbook as either an operational activity (water service) or a maintenance activity (water system). Water service data includes base unit quantities, total costs and unit costs per thousand gallons (k-gal) of water for purchased, surface (filtered) and ground water (unfiltered)

TABLE 2

INSTALLATIONS LOCATED IN THE CONTIGUOUS UNITED STATES
(Listed by Major Command)

USA Forces Command (FORSCOM)

Ft. Bragg, North Carolina
Ft. Campbell, Kentucky
Ft. Carson, Colorado
Ft. Devins, Massachusetts
Ft. Drum, New York
Ft. Hood, Texas
Ft. Indiantown Gap, Pennsylvania
Ft. Sam Houston, Texas
Ft. Lawton, Washington
Ft. Lewis, Washington
Ft. McCoy, Wisconsin
Ft. McPherson, Georgia
Ft. Meade, Maryland
Ft. Riley, Kansas
Ft. Sheridan, Illinois
Ft. Stewart, Georgia
National Training Center, California
Presidio of San Francisco, California
Vancouver Barracks, Washington
Yakima Firing Range, Washington
Ft. Ord, California
Ft. Polk, Louisiana

USA Training and Doctrine Command (TRADOC)

Ft. Belvoir, Virginia
Ft. Benning, Georgia
Ft. Bliss, Texas
Ft. Chaffee, Arizona
Ft. Dix, New Jersey
Ft. Eustis, Virginia
Ft. Gordon, Georgia
Ft. Benjamin Harrison, Indiana
Ft. A.P. Hill, Virginia
Ft. Jackson, South Carolina
Ft. Knox, Kentucky
Ft. Leavenworth, Kansas
Ft. Lee, Virginia
Ft. McClellan, Alabama
Ft. Monroe, Virginia
Ft. Hamilton, New York
Ft. Pickett, Virginia
Ft. Rucker, Alabama
Ft. Sill, Oklahoma
Ft. Leonard Wood, Missouri
Carlisle Barracks, Pennsylvania

USA Communications Command (ACC)

Ft. Huachuca, Arizona
Ft. Ritchie, Maryland

United States Military Academy

United States Military Academy, West Point, New York

TABLE 2 (Continued)

INSTALLATIONS LOCATED IN THE CONTIGUOUS UNITED STATES
(Listed by Major Command)

USA Material Development and Readiness Command (DARCOM)

Anniston AD, Alabama
Army Materials and Mechanics Research Center, Massachusetts
Harry Diamond Laboratories, Maryland
Letterkenny AD, Pennsylvania
Lexington-Blue Grass AD, Kentucky
McAlester AAP, Oklahoma
Navajo Depot Activity, Arizona
New Cumberland AD, Pennsylvania
Picatinny Arsenal, New Jersey
Pine Bluff Arsenal, Arkansas
Pueblo Depot Activity, Colorado
Red River Arsenal, Texas
Redstone Arsenal, Alabama
Rock Island Arsenal, Illinois
Rocky Mountain Arsenal, Colorado
Sacramento AD, California
Savanna AD, Illinois
Seneca AD, New York
Sharpe AD, California
Sierra AD, California
Tobyhanna AD, Pennsylvania
Tooele AD, Utah
Umatilla Depot Activity, Oregon
Ft. Wingate Depot Activity, New Mexico
Watervleit Arsonal, New York
Corpus Christi AD, Texas
Detroit Arsenal, Michigan
Ft. Monmouth, New Jersey
Jefferson Proving Ground, Indiana
St. Louis Area Support Center, Illinois
Aberdeen Proving Ground, Maryland
Dugway Proving Ground, Utah
Natick Development Center, Massachusetts
White Sands Missile Range, New Mexico
Yuma Proving Ground, Arizona

USA Health Services Command (HSC)

Ft. Detrick, Maryland
Fitzsimmons, Army Medical Center, Colorado
Water Reed Army Medical Center, District of Columbia

USA Intelligence and Security Command (INSCOM)

Arlington Hall Station, Virginia
Vint Hill Farms Station, Virginia

Military Traffic Management Command (MTMC)

Bayonne Military Ocean Terminal, New Jersey
Gulf Outport, Louisiana
Oakland Army Base, California
Sunny Point Military Ocean Terminal, North Carolina

(Source: FY 1981 Redbook)

operational activities. Water system data relates to treatment, filtration, wells and distribution maintenance activities, with annual quantities and costs given. Only average daily water use is recorded and it is shown as total annual water delivered throughout the installation. There is no further disaggregation into seasonal or sectoral water use.

The Redbook also provided data related to population approximations and real property measurements of building gross floor area and improved grounds acreage. This information was required to analyze existing Army water use estimation procedures and to empirically test the conceptualized water use model developed in Chapter V. A summary of the data obtained from the Redbook is given in Table 3 and each item is further discussed in the text of this study.

In this study, categorized total building areas are examined for variance differences in order to sum them into new variables that represent independent sectors of water use. Having identified the sectors using factor analysis to assist in this step, the sectors are subjected to regression analysis to determine their explanatory power. Improved ground acreage and evapotranspiration are also tested within the model. The details of this analysis are presented in Chapter V.

Other sources of data were reviewed for possible adaptation to the objectives of this study and are summarized in Table 4. Those noted as general references were most helpful in identifying points of contact and installation locations not commonly found elsewhere.

TABLE 3

REDBOOK RAW DATA SUMMARY

| Data Category | Type of Data | Unit of Measure | Description |
|---|---|---|---|
| Water Service Operation | Total Water Requirements | k-gallons per year | Total annual water requirements from purchased surface and ground water sources for each installation |
| | Unit Costs | dollars per k-gallons per year | Unit costs for water service operations disaggregated by source of water only |
| Water System Maintenance and Repair | Total Costs | dollars per year | Total annual costs for the maintenance and repair of treatment and filtration equipment, wells, and distribution system |
| Population | Effective population | persons | Average daily effective population includes all resident soldiers, families and a proportion of non-resident civilian and military personnel who work on each installation |
| Real Property | Building Gross Floor Area | k-sq. ft. | Total square footage of gross floor areas of all buildings aggregated into twelve non-overlapping functional categories |
| | Total improved grounds | acres | Intensively used ground areas where annual requirements for maintenance measures exist consisting of irrigation, dust control and others. |

TABLE 4

PUBLISHED SOURCES OF INFORMATION

| Type of Information | Source |
|---|---|
| Historic weather-related data | Local Climatological Data (National Oceanic and Atmospheric Administration, 1982a)<br><br>Climatological Data of the States (National Oceanic and Atmospheric Administration, 1982b)<br><br>Summer Precipitation and Potential Evaporation Contour Maps (Hittman Associates, Inc., Vol. 11, 1969) |
| Historic population data | Distribution of Personnel by State and by Selected Locations (Department of Defense, 1982) |
| Historic housing requirements | Determination of Housing Requirements (Department of Defense Report 1378) |
| Map Book | Major Military Installations (Department of Defense, 1980) |
| Installation Directories | Department of the Army (U.S. and World Government Installation Directory Service, 1982)<br><br>Department of the Army (U.S. Organization Chart Service, 1983)<br><br>Guide to Military Installations in the United States (<u>The Times Magazine</u>, 1982 and 1984)<br><br>Temporary Military Lodging (1981) |

## Installation Visits

Twelve installations were visited during the period 5 January - 29 January 1984 to conduct informal discussions with the Facility Engineer and/or his designated utility manager regarding water service, to obtain associated water supply data and reports and to tour water treatment plant facilities, when practical to do so. Additionally, four installation visits afforded a pretest of the mail survey instrument prior to release to all installations in the study area. Installations were selected to provide a representation of the Major Commands, principal mission activities, and geographical regions within the constraints of time and money limitations. The characteristics of the visited installations are shown in Table 5. Arrangements for each visit were coordinated in advance with the respective MACOM Engineers and each installation DEH. During these visits, discussions were held with 61 planners, utility supervisors and engineers experienced in the operation and maintenance of water systems on these installations. Without exception, the cooperation, candor and willingness to assist in this study were always apparent.

## Mail Survey - Purpose and Design

Preliminary discussions with researchers at the U.S. Army Construction Engineering Research Laboratory revealed a lack of an information base that could meaningfully characterize water use and water

TABLE 5

CHARACTERISTICS OF VISITED INSTALLATIONS

| INSTALLATION | MAJOR COMMAND JURISDICTION* | PRINCIPAL ACTIVITY | LOCATION |
|---|---|---|---|
| Ft. Campbell | FORSCOM | Readiness | Kentucky |
| Ft. Bragg | FORSCOM | Readiness | North Carolina |
| Ft. Sill | TRADOC | Training | Oklahoma |
| Ft. Bliss | TRADOC | Training | Texas |
| Ft. Belvoir | TRADOC | Training | Virginia |
| White Sands Missile Range | DARCOM | Test & Evaluation | New Mexico |
| Red River Army Depot | DARCOM | Supply Depot | Texas |
| Pine Bluff Arsenal | DARCOM | Arsenal | Arkansas |
| Harry Diamond Laboratories | DARCOM | Laboratory | Maryland |
| Walter Reed Army Hospital | HSC | Hospital | District of Columbia |
| Ft. Huachuca | ACC | Communication | Arizona |
| Ft. McNair | MDW | Capital Support | District of Columbia |

*Major Command acronyms are defined in Table 2.

planning experience and emphasis for the installations in the study area. It was this kind of information that would lend credibility to, or refute, the conclusions of the NDI assessment. Specifically, it was desired to know the extent and content of:

(1) Installation water use forecasts and the methods employed;

(2) Documented contingency plans for short-term water shortage events and the kinds of water conservation measures included in the plans; and

(3) Water conservation programs implemented in the recent past.

It was expected that the results of a survey targeted at all installations in the study area would reveal significant deficiencies in these water-related planning areas in line with similar indications drawn from installation visits. If actual practices confirmed these expectations, it would imply that the lack of emphasis and incentives indicated in the conclusions of the NDI study were confirmed.

Advance coordination was made with the Deputy Director for Facilities Engineering and Housing, Office of the Chief of Engineers and each MACOM Engineer prior to conducting the survey. Without their consent to proceed, it is unlikely that the survey would have received any response at the installation level. Permission was also given by the Commander, United States Army Student Detachment at Fort Benjamin Harrison, Indiana to use the Detachment official letterhead on the introductory letter accompanying the survey instrument and on the two follow-up letters. All letters carried the official signature block of this researcher, who is an active duty Army Officer in the Corps of

Engineers. The survey questionnaire and related letters are attached in Appendix A.

The target for the survey included all 90 installations in the study area and 3 additional installations in the Washington, D.C. area which are not reported separately in the Redbook. They are consolidated under the Military District of Washington (MDW) and, although there is no individual historic Redbook data regarding water service, their response concerning water planning activities was considered to be homogeneous with all other installations.

The survey instrument consisted of 17 questions. Questions 1 through 4 were designed to elicit replies for FY 1982 and 1983 water service data not available due to the non-publication of the Redbook for these two years. Questions 5 through 16 are directly related to the three areas of desired information described above and the first objective of this research. The questionnaire was pre-tested at 4 installations prior to releasing it to all targeted installations. There were no revisions required because the respondents during the pre-test indicated no obstacles in answering and were able to complete the questionnaire, on the average, in 2 hours.

A summary of the 86 respondents by job title is shown in Table 6, in accordance with their reply to Question 17. The average number of years employed by each respondent in their respective position was 5½ years, with a range from 1 month to 25 years. One respondent did not furnish a job title and 3 respondents did not indicate years of service. It was requested in the cover letter addressed to the DEH that the respondent chosen to answer the questionnaire be knowledgeable and experienced in

TABLE 6

SURVEY RESPONDENT JOB TITLE AND FREQUENCY

| Title | Absolute | Frequencies Relative (%) | Cumulative (%) |
|---|---|---|---|
| Chief/Assistant Chief of Utilities | 18 | 20.9 | 20.9 |
| Environmental Supervisor/Engineer/ Specialist/Coordinator | 18 | 20.9 | 41.8 |
| Director/Chief/Manager of Engineering and Housing or Facility Engineering | 14 | 16.3 | 58.1 |
| Chief, Sanitation Branch | 8 | 9.3 | 67.4 |
| Foreman/Supervisor, Water Treatment Plant or Main Pumping Station | 6 | 7.0 | 74.4 |
| Engineering Supervisor/Engineer/ Technician | 6 | 7.0 | 81.4 |
| Chief, Environmental/Natural Resources Branch | 4 | 4.6 | 86.0 |
| Chief, Maintenance Division | 2 | 2.3 | 88.3 |
| Master Planning Chief/Planner | 2 | 2.3 | 90.6 |
| Chief/Engineer, Mechanical Engineering Branch | 2 | 2.3 | 92.9 |
| Chief of Operations | 2 | 2.3 | 95.2 |
| Sub-area Commander | 1 | 1.2 | 96.4 |
| Deputy Director of Engineering and Housing | 1 | 1.2 | 97.6 |
| Administrative Officer | 1 | 1.2 | 98.8 |
| (Missing Job Title) | 1 | 1.2 | 100.0 |
| TOTALS | 86 | 100 | 100.0 |

the planning operation and maintenance of water supply activities and occupy a principal management position in this area. The listing appears to verify that the majority of respondents were selected to comply with this criteria.

The pre-test mailing occurred on 26 December 1983, followed by the first phase of the overall general mailing. Eight questionnaires were sent on 28 December 1983 to the remaining posts included in the installation visit itinerary. The cover letters were modified to instruct the DEH at each of these posts to retain the questionnaire for personal review and pickup during on-site discussions. The general initial mailing was released on 11 January 1984 with a requested reply date of 25 January 1984. Reminder letters were sent at approximately one-month intervals and the last received response was on 14 May 1984. The elapsed time for the survey was 141 days and resulted in 86 responses for a return rate of 92.5 percent (Table 7). The principal investigator conducted all phases of the entire survey operation, to include questionnaire design, mailing, interviewing, data collection, coding, tabulation and analysis, thus reducing potential reliability problems associated with the use of coding terms.

Each questionnaire was edited upon receipt in order to detect, and as far as possible, eliminate errors in the completed reply. Mailed returns were checked and missing entries were noted in 14 questionnaires. In most cases, a follow-up point of contact with telephone number was indicated in response to Question 17 and, when it was verified that the point of contact was also the original respondent, the missing data was obtained by telephone. A frequency analysis was used to describe the

TABLE 7

SURVEY MAILING RESULTS AND RESPONSE SUMMARY

| Survey Activity | Mailing Dates | Number of Mailings | Number of Responses |
|---|---|---|---|
| Pre-test mailing | 26 December 1983 | 4 | 4 |
| Initial mailing (cover letter and questionnaire) | 28 December 1983 (Phase I) | 8 | 8 |
| | 11 January 1984 (Phase II) | 81 | 45 |
| First reminder letter | 6 February 1984 | 36 | 25 |
| Second reminder letter with questionnaire | 12 March 1984 | 11 | 4 |

Summary:

Target number of installations - 93

Number of responses - 86

Response rate - 92.5%

results which are integrated into Chapter III. Hypothesis testing to determine systematic relationships between joint frequencies was accomplished using Chi-square analysis.

## Literature Sources Pertinent to Water Use Forecasting

The U.S. Water Resources Council (1983) recently approved the Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies to guide federal water resource development agencies in preparating and evaluating water-related projects. Benefit evaluation criteria for municipal and industrial water supplies include procedures for projecting future water use and require an analysis of those factors that may explain variations in the levels of water use. They include: (1) sector analysis (residential, commercial, industrial and other, such as public service use); (2) analysis by time of use (seasonal variations and maximum day use for each season); and (3) relationships between relevant determinants of water use and future expected levels. The theme of these requirements is to instruct agencies to deliberately improve water use forecasting procedures which historically have extrapolated a population growth curve to project future water supply needs at various time horizons. It has been indicated earlier that this latter practice, with some modification, is used on Army installations to estimate water quantities required to support peacetime demands.

The Corps of Engineers responded to these guidelines and has

prepared an excellent series of recent reports on municipal and industrial water use forecasting techniques which are hereafter referred to as the Annotated Bibliography (Dziegielewski, et al., 1981), the Forecasting Assessment (Boland, et al., 1981), and the Handbook of Methods (Boland, et al., 1983). These three documents provided the general platform for further scrutiny of related studies.

The Annotated Bibliography provided a review and general description of both published and unpublished water use forecasting literature. A total of 83 studies were referenced and further classified by forecasting methods and content. Studies were selected and obtained which described both single and multiple coefficient methods of prediction, but excluded demand models which are based on economic reasoning and include price and income among other independent model variables. The data requirement to test these variables against installation water use is not available due to the lack of meters and related pricing system for water.

A water use forecast can be defined as a conditional prediction of the level of water use at some future time horizon. A forecast is conditional based on the underlying assumptions related to the future expectations of the variables used in the model. If the assumptions are incorrect, it is likely that the forecast will also be inaccurate. Furthermore, a forecasting model must be capable of explaining observed patterns of water use before they can be implemented for prediction purposes (Boland, 1980). Single coefficient methods inhibit this capability while multiple coefficient methods enhance this process and are more in line with the requirements of the Principles and Guidelines. Studies pertinent to both methods are reviewed in Chapter IV.

## Summary

To accomplish the four research objectives, this study was divided into two basic tasks. The first task was to gather new information through a mail survey to the 90 installations in the defined study area that would describe the extent and content of water service planning and water conservation programs. This information would bear directly on the assessment of the validity of the conclusions of the National Defense Institute (NDI) study. The results of the survey pertinent to this objective are integrated into Chapter III.

The second task was related to achieving the remaining three objectives using the historical water service data of the Redbooks. Problems with existing water service estimation techniques are illustrated in Chapter IV, with a critical assessment of the measure of effective population to fulfill the goals of the second objective. Building gross area values for each installation are analyzed to determine representative sectors of installation water service, which are entered into a conceptualized model of water requirements, tested and interpreted in Chapter V.

Special considerations to features which may impact on installation approaches to water planning were presented at the opening of this chapter. Although there are similarities between civilian and military communities that suggest mutual water service planning techniques, the data bases and explanatory variables related to water use are different because of these features and are further examined in the following chapters.

## CHAPTER III

## WATER SERVICE AND RELATED MANAGEMENT PRACTICES WITHIN THE STUDY AREA

The National Defense Institute (NDI) study concluded with a prognosis of rising costs by the year 2000 for water service on Army installations. Expansion capabilities of Army posts may be constrained by inadequate water service, implying the need for accurately estimating current capabilities and for preparing contingency plans in the event of water shortage occurrences. Water conservation programs, when properly planned, can attenuate these adverse impacts but a lack of incentives to investigate the benefits of potential conservation measures may result in indifference by planners at the installation level and a corresponding lack of interest.

Is the Army actually experiencing a pattern of rising water related costs? Are water requirement studies being undertaken and contingency plans being developed for potential water shortage situations? Is water conservation being practiced or not? The answers are revealed herein and tend to verify the conclusions of the NDI assessment.

This chapter characterizes water service and the state of water planning within the study area. Average daily water use for the 90 installations during Fiscal Year 1981 is described relative to mission orientation, i.e., Major Command and sources of water. Analysis by population size and per capita water use indicators would be misleading

because of errors in population measurement that are described in Chapter IV.

The analysis then concentrates on the status of water planning and conservation practices among Major Commands. Data obtained from the survey are analyzed to provide a perspective on the scope and intensity of water planning effort in the study area. Distribution patterns of planning activities are statistically assessed to determine the presence of systematic relationships. This analysis provides partial explanations of why some installations have planned for water shortages, conducted water use forecasts, and implemented water conservation programs -- and why others have not.

The distribution of unit costs for water service operation and water system maintenance and repair are analyzed by mission orientation and sources of water supply. Average unit costs are pursued to determine the significance of trends for the period FY '75 through FY '81.

## Installation Locations in the Study Area

The 90 installations are located within the defined study area as shown on Figure 1. There are a variety of reasons why any given installation may be located where it is: to facilitate realistic training in various terrain and climatic environments or to provide logistical support at major transportation terminals for movement of troop units and supplies, and of course, to ensure national security. Still others, such as Fort Leavenworth, Kansas and the United States Military Academy at West Point, New York are major centers of military


Figure 1. Location of Installations within the Study Area.

education, as well as historic landmarks. They are sited and maintained for specific mission purposes.

Commercial and industrial growth would most likely occur due to changes in mission orientation. For example, the addition of a major troop unit, such as a brigade, to permanent residency on a selected post may require additional community support activities if existing facilities are overly strained. Increased industrial production of Army equipment or broadened research and testing of improved weapon systems or ammunition may also require expanded facilities. Generally, however, some growth would take place when old facilities are replaced by modern housing and additional commercial activities which improve the quality of life of soldiers and their families.

## Installations Grouped by Mission Orientation

A valid indicator of the mission orientation of an installation is the name of the Major Command to which it is assigned. For example, Forces Command's (FORSCOM) mission is to keep Army forces ready for deployment. Installations within FORSCOM, therefore, are characterized by a day-to-day emphasis on operational readiness of all Army component units working together under detailed plans for mobilization. Training and Doctrine Command (TRADOC) provides training for all soldiers as well as doctrinal and training publications and maintains jurisdictional control over Army branch schools and training centers. Examples include Ft. Belvoir (the Engineer Center), Ft. Benning (the Infantry Center) and Ft. Sill (the Field Artillery Center). On the other hand, installations

within the Army's Material Development and Readiness Command are involved in the development, test and evaluation, procurement, distribution, maintenance and disposal of nearly all Army equipment. These three Major Commands alone account for 80 percent of all the installations within the study area.

There are eight Major Commands controlling the individual installations listed in the FY 1981 Redbook (Table 8) and one additional Command, the Military District of Washington that controls three subordinate stations in the Metropolitan area of Washington, D.C. Permission was obtained from this last Command to survey the three posts to assess water planning activities; however, they are not reported individually in the Redbook data base. Within each command, the installations are generally distributed throughout the study area and there are no discrete geographical boundaries among them. The common acronyms of the Major Commands will be used to represent the mission orientation of corresponding installations. A listing of installations by Major Command was previously given in Table 2 (p. 25). A total of 83 installations represent the Major Commands in both the FY 81 Redbook and the survey which facilitated a joint analysis between the two data bases.

## Water Service Patterns Within the Study Area

Installations may have either single or multiple sources of water supply. Water service may depend on acquired surface or ground water sources and transmission, filtration and distribution are accomplished by the DEH workforce. On the other hand, post water needs may be purchased

TABLE 8

MAJOR COMMAND IDENTIFICATION AND SELECTED CHARACTERISTICS

| Major Command Designation | Common Acronym | Number of Installations Within the Study Area | | Mission Orientation |
|---|---|---|---|---|
| | | FY 81 Redbook | Survey Respondent | |
| Forces Command | FORSCOM | 22 | 20 | Operations and unit readiness. |
| Training & Doctrine Command | TRADOC | 21 | 18 | Manages individual soldier training; commands the Army's service schools; development of doctrine & training publications. |
| Material Development & Readiness Command | DARCOM | 35 | 33 | Manages the Army's total logistics system and controls various research & development and material readiness installations. |
| Intelligence and Security Command | INSCOM | 2 | 2 | Intelligence collection and production, counterintelligence and security. |
| U.S. Army Communications Command | USACC | 2 | 2 | Plans, engineers, installs and operates the Army's portion of the Defense Communications System and for other Army communications and air traffic control facilities. |

TABLE 8 (Continued)

MAJOR COMMAND IDENTIFICATION AND SELECTED CHARACTERISTICS

| Major Command Designation | Common Acronym | Number of Installations Within the Study Area | | Mission Orientation |
|---|---|---|---|---|
| | | FY 81 Redbook | Survey Respondent | |
| Military Traffic Management Command | MTMC | 4 | 4 | Manages all military traffic, land transportation and common-user ocean terminals. |
| Health Services Command | HSC | 3 | 3 | Manages and delivers health care and supportive services and supervises medical training for the Army. |
| United States Military Academy | USMA | 1 | 1 | Provides the Army with well-educated and highly trained professional Army officers. |
| Military District of Washington | MDW | NA | 3 | Responsible for designated Army functions in the metropolitan area of Washington, D.C. |
| | TOTALS: | 90 | 86 | |

from local civilian communities and transmitted to the installation for delivery through its distribution system. Of course, purchased water is either surface or ground water but is discussed here as a separate entity to point out that installations are not necessarily self-supporting with their own private water source.

Army Regulation 37-100-81 defines purchased water as the total quantity of water purchased under utility contracts. Filtered water, termed here as surface water, is the total quantity of water produced by installation filtration plants. Unfiltered water represents ground water and is defined as the total quantity of water produced through the operation of wells, cisterns, springs and other equipment located in pumping stations. The categories are non-overlapping and the sum of the three categories is the total water service requirement for any particular installation. The total average daily water requirement for all 90 installations in FY 81 was 163.1 million gallons per day (mgd). The mean value per installation is 1.8 mgd with a low value of 12,000 gallons per day at Ft. Wingate Depot Activity in New Mexico to a high of 9.8 <u>million</u> gallons per day at Redstone Arsenal, Alabama. The distribution of average daily water use was assessed and is shown by source with further disaggregation by Major Command in Table 9.

## Single versus Multiple Sources of Water Supply

Forty-two installations (46.6%) obtain their daily water needs from a single source of supply and together account for 18 percent of the total water used on an average day within the study area. The remaining

TABLE 9

INSTALLATION MEAN AVERAGE DAILY WATER REQUIREMENTS BY MAJOR COMMAND AND SOURCE OF WATER SUPPLY
(Millions of Gallons Per Day)

| Major Command | Sources of Water Supply | | | | | | | | Percentage of Total Average Daily Water in Study Area |
|---|---|---|---|---|---|---|---|---|---|
| | Single Source | | | Multiple Sources | | | | | |
| (Mission Orientation) | Purchased | Ground | Surface | Purchased + Ground | Purchased + Surface | Ground + Surface | Purchased + Ground + Surface | Totals | |
| FORSCOM | 0.47(4) | 0 | 0 | 5.73(2) | 3.06(12) | 0 | 3.66(4) | 64.70(22) | 39.7 |
| TRADOC | 1.22(5) | 2.05(1) | 0.10(1) | 1.98(4) | 2.97(4) | 2.26(1) | 4.26(5) | 51.61(21) | 31.6 |
| DARCOM | 0.45(9) | 1.33(5) | 0.41(9) | 0.25(1) | 0.29(3) | 1.18(4) | 3.88(4) | 35.75(35) | 21.9 |
| USACC | 0 | 0 | 0 | 0 | 2.68(1) | 0 | 0.44(1) | 3.12(2) | 1.9 |
| HSC | 1.08(2) | 1.59(1) | 0 | 0 | 0 | 0 | 0 | 3.75(3) | 2.3 |
| INSCOM | 0.16(1) | 0 | 0.23(1) | 0 | 0 | 0 | 0 | 0.39(2) | .3 |
| MTMC | 0.25(3) | 0 | 0 | 0 | 0.10(1) | 0 | 0 | 0.85(4) | .5 |
| USMA | 0 | 0 | 0 | 2.97(1) | 0 | 0 | 0 | 2.97(1) | 1.8 |
| Total Average Day Requirements | 15.10(24) | 10.29(7) | 4.02(11) | 22.60(8) | 52.25(21) | 6.98(5) | 51.90(14) | 163.14(90) | 100 |
| Percentage of Total Average Daily Water in Study Area | 9.3 | 6.3 | 2.5 | 13.8 | 32.0 | 4.3 | 31.8 | 100 | |

*Average values are shown for the number of installations given in parentheses.

48 installations are serviced by multiple sources of water which account for 133.73 mgd or 82 percent. Within the categories of single sources, purchased water from local civilian communities ranks the highest in terms of total water needs (15.1 mgd) among single source installations; however, on a per installation basis, stations depending on ground water consume greater average daily quantities of water (1.47 mgd) than those that purchase water (0.36 mgd) or those posts that utilize a surface water source (.63 mgd).

Among multiple source posts, the dual combinations of purchased and surface water (52.25 mgd) or purchased and ground water (22.60 mgd) satisfy the needs of 29 installations (32%). Nearly one-third of all water (51.9 mgd) required on an average day by all installations in the study area is provided by systems which combine all three sources of water.

It is evident that the larger users of water (above the grand mean of 1.8 mgd) are served by multiple sources. Average use by installation ranges from 0.25 mgd to 5.73 mgd with a mean for all multiple source installations of 2.79 mgd. On the other hand, single source installations reflect a range from 0.10 mgd to 2.05 mgd with a mean for all single source installations of 0.70 mgd.

## Water Use by Mission Orientation

Forces Command (FORSCOM), Training and Doctrine Command (TRADOC), and Material Development and Readiness Command (DARCOM) collectively account for 93.2 percent of the Army's water needs within the study area.

FORSCOM uses the greatest proportion (39.6%) of the total daily water requirement followed by TRADOC (31.6%) and then DARCOM (21.9%). A comparison of the mean values for all installations within each of these three Major Commands reveals the same rank ordering. A typical installation in FORSCOM uses 2.94 mgd which is about 20 percent more than the average TRADOC post (2.45 mgd) and almost twice as much (188%) as an average DARCOM installation (1.02 mgd). It can also be observed that both FORSCOM stations (82%) and TRADOC posts (67%) are predominantly multiple source. The reverse is true for DARCOM installations where 66 percent of all the installations with a mission orientation of logistics supply or material development and testing receive their water from single sources. When all of the remaining five commands are grouped into a single category termed "all others" it was determined that the average daily water requirement is 0.92 mgd per installation and considerably below the average for the entire study area (1.8 mgd).

The number of sources of water appears to be related to mission orientation. Installations with troop unit orientation of operational readiness (FORSCOM) and soldier training (TRADOC) tend to have multiple sources of water supply. Additionally, these two commands also use more per installation than the grand mean average daily water requirement. A reverse relationship emerges for DARCOM installations and the twelve installations grouped as "all others." These stations generally use less than the population mean daily water value and are likely to depend on a single source for their water supply.

## Water Use by Total Building Area

An additional qualifier of average daily water use was sought to provide a partial explanation of why FORSCOM and TRADOC installations generally use water quantities greater than the mean for the initial population of 90 installations. It may be that the posts with these mission alignments provide water service to populations larger than the average population. Unfortunately population data is suspected of being measured incorrectly and the reasons why are discussed in Chapter IV. An alternative measure is the total gross floor area of all buildings located on each installation. Moreover, building floor area is a kind of surrogate for population and the types of buildings can also suggest the mission orientation of an installation. Within the study area, the mean value for total building area is 6.7 million square feet with a minimum value of 131 thousand square feet at Sunny Point Military Ocean Terminal, North Carolina and a high value of 23.1 million square feet at Fort Hood, Texas. It is reasonable to suspect that installations with greater than average total building areas would also likely be greater than average water users. Having observed that FORSCOM and TRADOC installations are generally above average water users then it is also likely that they also have greater than average building areas.

## Statistical Analysis of Water Use Relationships

These observed or suspected relationships were used to formulate corresponding hypotheses and were empirically tested using joint

frequency analysis between pairs of variables representing average daily water use, source of water, mission orientation, and total building floor area. Average daily water use was divided about the population mean in order to distinguish installations which were "above average" and "below average" water users. Sources of water were grouped into the two principal categories of "single" or "multiple" sources. Mission orientation for each installation was represented by its parent Major Command. Total building square footage was also separated at the population mean for this variable. In each hypothesis examined, the statistical analysis failed to reject the null hypothesis that the observed frequencies were not different from the expected distribution (Table 10). Moreover, an examination of the individual cells in each test verified the observations provided by Table 9. Total building area was strongly related to average daily water use as indicated by the high level of statistical significance of the Chi-square and there exists a significant positive correlation on installations between above average water use and above average building floor area (r=0.674). Additionally, the total size of building area depends in part upon the mission orientation of the installation. Here again, FORSCOM and TRADOC installations were found to have total building areas above the average. Logistical installations (DARCOM) and generally the remaining Major Commands use less than average daily water quantities and are also below average in total building gross floor area.

TABLE 10

JOINT FREQUENCY ANALYSIS OF AVERAGE DAILY WATER USE PATTERNS

| Dependent Variable | Independent Variable | Chi-Square | Degrees of Freedom | Level of Significance | Pearson's R | Level of Significance |
|---|---|---|---|---|---|---|
| Average Daily Water Use | Major Command | 20.347 | 7 | 0.0049 | -0.318 | 0.0011 |
| Average Daily Water Use | Source of Water | 28.928 | 1 | 0.0001 | 0.567 | 0.0001 |
| Average Daily Water Use | Total Building Area | 40.833 | 1 | 0.0001 | 0.674 | 0.0001 |
| Source of Water | Major Command | 23.404 | 7 | 0.0014 | -0.369 | 0.0002 |
| Source of Water | Total Building Area | 14.405 | 1 | 0.0001 | 0.400 | 0.0001 |
| Building Area | Major Command | 20.490 | 7 | 0.0046 | -0.353 | 0.0003 |

## Water Use Patterns Within the Study Area: Conclusions

Why do some installations use more water on an average day than others? Those that use more than approximately 1.8 mgd are likely to have the mission orientations by FORSCOM and TRADOC (operational readiness and soldier training), to have multiple sources of water supply, and have above average total building floor area. Those stations which use less than 1.8 mgd are likely to have missions related to logistical support and material development (DARCOM), to have single-sourced water supplies and to be below the population mean for total building floor area.

It may be reasonable to expect that those posts aligned with missions of intensive field training, mobilization and deployment planning, and community support requirements for thousands of soldiers and their families would also tend to be sensitive to life support systems, particularly water service requirements. Because they are also above average water users, they are likely to be aware of future water needs as well as the impacts of a water shortage and have planned for such events. The presence of implemented water conservation measures would be more probable on these stations. On the other hand, it has been determined that these same installations usually have multiple sources of water, which may imply that back-up systems are ready to cope with short-term water emergencies and long-term expansion programs.

Conversely, logistical installations--supply depots, ammunition production and storage points and material development and research stations--use comparatively less water, although use may be intensive.

Total building area is also less, suggesting smaller populations for which water must be furnished. Although speculative, it may be that posts that fit this pattern may be less likely to evaluate potential conservation measures. Nevertheless, one would still expect water planning actions associated with water shortage contingencies and water requirement forecasts. These suppositions were further investigated during installation visits and from data obtained in the mail survey and are investigated in the sections that follow.

## Water Planning Insights from Installation Visits

It was reasonable to conceive that supplemental water planning guidelines may have been promulgated by the Major Commands and were being practiced at these installations. There was no evidence to support these suppositions. With the exception of two installations in the Southwest, water supplies were considered more than adequate for present and future peacetime requirements. This consensus was usually based on the judgment that water service was being operated below water system capacities. At the same time, however, studies had not been done on these installations to determine the major users of water and quantities of water used. The absence of water studies was generally attributed to the lack of water meters. Water utility personnel conceded that water losses and water waste are occurring but have not been quantified. The potential dollar benefits of water conservation measures are not viewed from the perspective of reducing loss or waste of water. Water service operation and system maintenance costs are considered small, compared to energy

costs which are receiving major planning emphasis and a well-defined conservation effort. In fact, water conservation is encourag.d primarily to reduce energy costs.

During these visits, six studies were obtained that projected water use requirements to support mobilization levels in a troop build-up scenario. Guidelines for the computation of the expansion capability of an installation to support the water requirements of increased soldier numbers and related equipment is provided in Army Regulation 420-16 (1982c). There is no corresponding requirement to prepare a separate forecast of water use in a peacetime setting. Yet, in calculating mobilization water requirements, it was noted during a review of these studies that it is necessary to estimate non- mobilization water requirements that will continue to use installation supplies during a build-up operation.

The procedures employed estimate average daily water use based on recent historical per capita usage and are discussed in detail in Chapter IV. The procedures assume that the derived per capita figure is appropriate to use in computing peacetime requirements, regardless of when mobilization would occur in time. The estimated current water use is then deducted from the rated capacities of major system components: source, pumps, treatment facilities, distribution lines and storage to estimate the remaining water service support capability. If inadequate to achieve the support levels of the mobilization contingency, engineering estimates are made to determine the size and costs to expand the water systems to achieve mission requirements.

There are at least three observations that can be made that cast doubt on the reliability of estimation involved in this procedure. If one accepts the peacetime water use approximation, will it continue to be valid in 5 years? 10 years or longer? Is peacetime water use expected to increase or decrease in these future time horizons? These questions need to be answered before decisions are made to expand water systems. The procedure assumes that non-mobilization water use will remain the same as it was at the time the study was conducted. Secondly, the per capita estimation technique assumes homogeneous water use throughout the installation and does not offer a means to assess separate impacts on domestic, commercial or industrial water which may differ considerably in a mobilization setting. The third observation is that, in each of these six studies, water conservation measures are expected to enhance water availability during expansion but the full range and types of potential conservation actions are not identified, assessed or rank ordered.

It is clear from the experience and insights gained through these installation visits that water service planning needs improvement in predicting peacetime water use, identifying sectoral usage and evaluating potentially beneficial conservation measures. Planners appear to have resolved that without meters to measure water use, the current Army planning guidelines are better than none at all. This observation is not intended to criticize but to merely describe the state of the water service planning environment. Nor are these observations necessarily indicative of all Army installations. Still, there were strong suggestions that the conclusions of the National Defense University assessment--inadequate water service to support mobilization

requirements and the lack of incentives to evaluate water conservation measures to reduce the impact of water shortages--were valid in most cases.

## Future Expectations of Water Source Requirements

An added insight can be gained by inquiring if purchased water requirements will increase in the near future. Installation water utility managers were asked to indicate whether purchased water will increase, decrease, or remain about the same by FY 1990. The same question was asked regarding surface and ground water sources. Seven Redbook installations did not respond to the survey and three posts from the Military District of Washington did reply but are not identified individually in the Redbook data base.

The percentages for each source have been adjusted to exclude posts where the source is not applicable or under consideration as a potential supplemental source (Table 11). Purchased water is expected to increase on 12 installations. Surface and ground water requirements are also anticipated to increase on 9 and 19 installations respectively. Within each source category, about half of the installations are reported as expecting current source water requirements to remain about the same.

A substantial number of respondents (29 separate installations) indicated that they did not know if source requirements would increase, decrease or remain the same by FY 1990. When uncertainties about future water requirements prevail, installation utility planners should have procedural guidelines available to assess future water needs. Knowledge

TABLE 11

WATER REQUIREMENTS FROM EXISTING SOURCES: FY 1990
EXPECTATIONS OF INSTALLATION WATER PLANNERS AND MANAGERS
(Number of Installations)

| Expectation | Source of Supply* | | |
|---|---|---|---|
| | Purchased Water<br>N % | Surface Water<br>N % | Ground Water<br>N % |
| Increase | 12 (21.0%)** | 9 (19.6%) | 19 (29.2) |
| Decrease | 1 (1.8%) | 0 (0%) | 3 (4.6%) |
| Remain about the same | 26 (45.6%) | 23 (50.0%) | 29 (44.6%) |
| Don't know | 18 (31.6%) | 14 (30.4%) | 14 (21.6%) |
| Source not applicable | 29 | 40 | 21 |
| Total Respondents | 86 (100%) | 86 (100%) | 86 (100%) |

* An installation may be included in more than one category if it depends on multiple sources.

**Percentages in parentheses are relative frequencies adjusted to exclude "Source not applicable" responses.

(Source: 1984 Survey of Water Use on Army Installations)

of expected needs is especially critical in the event of a water shortage compounded by an emergency mobilization mission.

This pattern of expectations is important because it implies that an assumption of present stationary water requirements sufficing future peacetime water service needs is not valid for a significant number of installations. Expansion capability planning must account for changes in peacetime water needs when changes are anticipated. Moreover, evaluation should be made using acceptable forecasting procedures.

The survey data, however, represent only the judgment or opinion of the planner or manager and may or may not be based on a future water service study. Pure judgmental or collective methods are not acceptable in forecasting water requirements (Boland, et al., 1983; Boland, 1980, 1978; Crews and Baumann, 1984). Were these responses from installation water utility personnel based on judgment or were they founded on a recent water requirement forecast? If studies have been accomplished, what methods were used in the analysis and for what purpose were the studies undertaken?

## Recent Water Requirement Studies

Installation water service planners and managers were asked if there had been a study done within the past five years that included a forecast of future installation water needs. From the total 86 respondents, 63 indicated "No" (73%), while 22 (26%) indicated that a study had been done; one respondent noted that a study was currently ongoing. Only about one-fourth of all responding installations have apparently

evaluated water needs for the future using a method that goes further than judgmental planning. Yet, at least half of the installations reported that their water needs in the future were uncertain or would increase. There are, therefore, voids in water service planning and forecasting that requires emphasis and improved forecasting studies to substantiate current planners expectations.

Among the 22 completed studies, 82 percent are based on a per capita or adjusted per capita forecasting method. Except for one forecast done in-house by DEH personnel, all others were prepared by Corps of Engineer District consultants or District personnel. It is not surprising that the per capita approach is the dominant forecasting method because Engineer Technical Bulletin 354 prescribes this approach, particularly when assessing installation expansion capability. The dominant forecast units were average day and annual water use in about 70 percent of the reported studies which were based upon monthly water service and population data obtained directly from the installation. Army guidance recommends these measures of water use, as well as maximum day use. Therefore, having found some evidence of water planning inadequacy in forecasting, it is desirable to present the survey analysis of other planning areas, specifically water shortage contingency planning and water conservation.

## Water Shortage Contingency Plans

It is reasonable to assume that installation water planning would include documented contingencies for implementation in the event of a

water shortage situation. A short-term water shortage may occur because of drought, contaminated water quality, major breaks in transmission or distribution lines, pumping station or treatment plant interruptions, and emergency mobilization requirements or combinations of any of these. It is also suggested that an absence of such plans may reflect that water is not expected to be affected by these causes or that spontaneous reaction in the event of occurrence will suffice to cope with the problem. Water shortages caused by drought, equipment failure and contaminated supplies have occurred on Army installations and warrant well-prepared and coordinated plans to contend with these potential crises.

## Contingency Plans and Mission Orientation

There were 51 (60%) installations responding to the survey that indicated that no documented plans were on-hand. One additional installation abstained from answering the question. To determine if a significant relationship existed between water emergency contingency plans and mission orientation, a two-way analysis of joint frequencies was conducted with "contingency plans" as the dependent variable and Major Command representing the independent variable (Table 12). Major Commands with four or less installations were grouped together into an "all others" category. The specific interest was to ascertain if FORSCOM and TRADOC installations have a greater than expected occurrence of water contingency plans. Their mission orientation, above average water use, and larger than average service area (building gross floor area) suggests

TABLE 12

WATER SHORTAGE CONTINGENCY PLANS AND MISSION ORIENTATION

| Contingency Plan Status | Mission Orientation | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FORSCOM | | TRADOC | | DARCOM | | ALL OTHERS | | | |
| | N* | % | N | % | N | % | N | % | N | % |
| None | 6 | 11.8 | 8 | 15.7 | 29 | 56.9 | 8 | 15.6 | 51 | 60.0 |
| Plan Prepared | 14 | 41.2 | 9 | 26.5 | 4 | 11.8 | 7 | 20.5 | 34 | 40.0 |
| TOTAL | 20 | 23.5 | 17 | 20.0 | 33 | 38.8 | 15 | 17.7 | 85 | 100.0 |

*Number of responses

Chi-Square = 29.472 with 3 d.f.

Probility Significance <.0001

this hypothesis. The results of the test indicate a strong relationship between contingency plans and mission orientation with a Chi-square level of significance at 0.0001. The analysis also shows that FORSCOM and TRADOC installations combined account for 25 (68%) of the total 34 installations reporting on-hand contingency plans. In contrast, DARCOM installations exceed expectations for "no plans" with 29 (57%) of all posts in this response group. It is apparent that stations supporting major troop units in a readiness posture are more likely to be sensitive to potential water supply emergencies than posts with material acquisition or storage functions and prepare contingency plans accordingly.

## Contingency Plans and Sources of Water Supply

It is reasonable to hypothesize that installations with only a single source of water supply would be more likely to develop plans for implementation to counter potential water shortage situations. With the status of contingency plans as the dependent variables, its distribution throughout the population was examined correspondingly with the frequency of single and multiple sources of water. The relationship was significant at the 0.02 level with a Chi-square value of 5.362. The correlation between the two variables was positive with $r = .251$, significant at a level of 0.01 probability. Single source installations have a greater than expected number without contingency plans, while stations with multiple sources of water supply have more plans than expected within the population. This finding raises a concern regarding

installations without plans and dependent on a single source of water supply. It may be that reserve supplies are readily available but procedures to get the supplies released during an emergency are not documented. Water utility managers would be well advised to prepare a written plan that would minimize costs to deal with a crisis situation.

## Types of Documented Water Shortage Contingency Plans

The type of emergencies planned by the 34 installations which do have written plans are shown in Table 13. By grouping the individually coded categories into single themes, it can be seen that the water shortage most frequently planned for was drought (18 plans) followed by contingencies to engage emergency mobilization water needs (14 plans). There are 8 installations which deal with contaminated water quality and an equal number that have documented plans to relieve water shortages due to a mechanical failure in the water system or power outage. Yet, the majority of installations responding to the survey indicate that plans are not on-hand and it is clear that the lack of plans means lack of water service planning.

## Recent Water Conservation Programs

Information pertaining to water conservation activities was sought to ascertain the extent and kinds of recent conservation measures implemented in the study area. In response to the question, "Has your installation implemented a water conservation program within the past

TABLE 13

WATER SHORTAGE CONTINGENCY PLANS

| Type of Contingency | Installations N | % |
|---|---|---|
| No documented plan on hand | 51 | (60.0) |
| Drought | 8 | (9.4) |
| Emergency Mobilization | 5 | (5.9) |
| Contaminated Water Quality | 3 | (3.5) |
| Mechanical Failure | 7 | (8.2) |
| Drought and Mobilization | 5 | (5.9) |
| Drought and Contaminated Quality | 2 | (2.4) |
| Mechanical Failure and Mobilization | 1 | (1.2) |
| Drought, Mobilization and Contaminated Quality | 3 | (3.5) |
| (Missing Response) | 1 | -- |
| TOTAL | 86 | 100 |

(Source: 1984 Water Use Survey)

five years?", 55 (64%) installations reported that they had not done so, 30 (35%) indicated "yes", and one installation did not respond to this particular question. The 30 installations further identified a combined total of 80 water conservation measures which, for the most part, were briefly described with reasons for selection and with results of implementation.

## Water Conservation Programs Within Major Commands

In order to determine if a systematic relationship exists between the distribution of implemented conservation programs and mission orientation, it was hypothesized that the presence of conservation programs would be more likely to occur at FORSCOM and TRADOC installations as compared to DARCOM and "All Other" Major Commands. Applying a criterion of 0.05 probability level for the significance of the Chi-square statistic, it was found that the relationship between practiced conservation programs and mission orientation was not significant (Table 14) for the surveyed population. An examination of the patterns between Major Commands reveals that FORSCOM installations account for 13 (44.8%) of the total implemented programs, but this quantity is identical to the expected distribution quantity. TRADOC installations, however, account for 11 (37.9%) of all implemented programs in the study area and this amount does exceed statistical expectations. Logistically-oriented posts and the comparatively smaller Major Commands exhibit fewer programs than expected based on the population distribution, but collectively the relationship is weak.

TABLE 14

WATER CONSERVATION PROGRAMS AND MISSION ORIENTATION

| Water Conservation Program Status | Mission Orientation | | | | | | | | Totals | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FORSCOM | | TRADOC | | DARCOM | | ALL OTHERS | | | |
| | N* | % | N | % | N | % | N | % | N | % |
| No program | 13 | 22.6 | 8 | 14.6 | 25 | 45.4 | 9 | 16.4 | 55 | 64.7 |
| Program implemented in the past five years | 7 | 23.3 | 9 | 30.0 | 8 | 26.7 | 6 | 20.0 | 30 | 35.3 |
| TOTALS | 20 | 23.5 | 17 | 20.0 | 33 | 38.8 | 15 | 17.7 | 85 | 100 |

*Number of Responses
Chi-square = 3.784 with 3 d.f.
Probability Significance = 0.466

Water conservation programs are generally distributed without significant differences throughout all Major Commands and the presence of an operationalized water conservation program is not significantly related to mission orientation.

## Water Use and Water Conservation Programs

The occurrence of executed water conservation programs is systematically related to the average daily water usage pattern throughout the study area. This conclusion followed a test of the hypothesis that water conservation programs are likely to occur on installations with above average water use. With the "status of water conservation" as the independent variable the joint frequency analysis resulted in a Chi-square value of 7.745, significant at the 0.0054 level for one degree of freedom (Table 15). More than three-fourths of the installations with no water conservation programs are below average water users and more than one-half of the posts with water conservation programs affected within the past five years are above-average water users. The correlation coefficient ($r = .307$) was also highly significant. The hypothesis cannot be rejected. Water use data was not available for the three stations in the Military District of Washington.

## Types of Conservation Measures Being Implemented

Restrictions and bans are most frequently implemented and collectively account for 55 percent of the aggregate total (Table 16).

TABLE 15

WATER CONSERVATION PROGRAM STATUS AND
AVERAGE DAILY WATER USE

| Status of Water Conservation Program | Average Daily Water Use | | | | Total | |
|---|---|---|---|---|---|---|
| | Below Average | | Above Average | | | |
| | N* | % | N | % | N | % |
| No program | 40 | 76.9 | 12 | 23.1 | 52 | 63.4 |
| Program implemented within past five years | 14 | 46.7 | 16 | 53.3 | 30 | 36.6 |
| TOTALS | 54 | 65.9 | 28 | 34.1 | 82 | 100.0 |

*Number of Responses
Chi-square = 7.745 with 1 d.f.
Probability Significance = 0.0054
r = .307
Significance = .0025

TABLE 16

SUMMARY OF RECENTLY IMPLEMENTED CONSERVATION MEASURES

| Type of Measure | Description | Reported as having applied during past 5 years N | % |
|---|---|---|---|
| Restrictions/Bans | Family/bachelor soldier lawn areas | 15 | (18.7) |
| | Golf course irrigation | 12 | (15.0) |
| | Car washing | 9 | (11.2) |
| | Tactical vehicle washing | 8 | (10.0) |
| Technology | Shower flow-control devices | 11 | (13.8) |
| | Reuse/recycle systems | 8 | (10.0) |
| | Faucet flow restrictors | 3 | (3.8) |
| | Water efficient tank commodes | 2 | (2.5) |
| Institutional | Leak detection studies | 3 | (3.8) |
| | Water conservation regulations | 2 | (2.5) |
| | Inspection of hot water heaters and boilers | 2 | (2.5) |
| | Centralizing tactical vehicle wash areas | 1 | (1.2) |
| | Conversion to desert landscape | 1 | (1.2) |
| Educational | Requesting voluntary cutbacks through various media | 3 | (3.8) |
| TOTALS | | 80 | (100.0) |

Irrigation restrictions of lawn areas and golf courses include alternate day, time of day and percent reduction controls. Bans or limitations on washing privately-owned cars and military tactical vehicles are also imposed. The primary reason for selection of these measures is to reduce nonessential water use during dry summer periods or a drought occurrence and enforcement is carried out by the post military police. These measures are therefore short-term mitigation actions during emergency water shortage situations. Results of implementation expressed by the study participants are qualitative, not quantitative. For example, responses include, "Quick way of coping with an emergency", "Met water reduction goal and no impact on mission", "Satisfactory reduction", and "Used less water".

Technological measures include *flow restrictive plumbing* fixtures or devices for faucets, shower heads and toilets. Among the reasons cited for choosing these measures were "To conserve water", "Energy conservation suggestion", "Reduced utility energy consumption", and "Cost effective". Shower flow-restrictors installed on four posts resulted in customer complaints and, in one case, they are being removed. Six installations noted specifically that they have not measured water reduction due to these devices and only one respondent stated explicitly the average daily quantity reduction per family attributable to these devices. Other technological measures taken were to reuse treated waste- water to irrigate the golf course and to wash military vehicles, and recycling water in cooling and heating processes to reduce make-up quantities. These actions resulted in large water reductions and related energy cost savings.

Two installations reported that they had implemented post-wide water conservation programs in the form of a regulation requiring compliance by all installation water users. One post indicated that water consumption was reduced by about 2 million gallons per day (mgd) because of its implementation and enforcement during dry summer months. Additional institutional measures such as leak detection studies, centralization of tactical vehicle wash areas and inspection of hot water heaters and boilers by the DEH workforce have been implemented. One post in the Southwest has begun selected conversion from grassed landscape to desert landscape to reduce irrigation water requirements.

Educational programs have been attempted at three installations where the emphasis has been to request voluntary cooperation by residents during peak water demand periods or to reduce water waste. Examples include showering once a day and washing dishes or laundry with a full load.

## Conclusions Pertinent to Water Conservation Planning

It was found that water conservation programs are systematically related to patterns of average daily water use. Installations with above average daily water requirements are likely to have implemented a water program within the past five years, while those with below average daily needs tend to be without a conservation program. The presence of an executed conservation program is not significantly related to mission orientation, and this finding is not surprising. There was no evidence to suggest that any of the Major Commands had promulgated a water

conservation policy addressing the potential for mission enhancement through water conservation. Of course, there is no policy at the highest level, Department of the Army, upon which Major Commands could formulate their own specific guidance to Installations Commanders under their jurisdiction. Although conjectural, it would appear reasonable to assume that such policies and guidelines would stimulate a greater than observed interest in the study area. Individual installations are on their own to determine the potential benefits of specific water conservation measures with no real incentives to pursue such a study.

Installation commanders exercise the final approval of a recommended water conservation measure and it is reasonable to assume that prudent decisions to adopt a measure can be made if the planners' submitted analysis reflects a full range of potential measures that would have applicability and customer acceptability. Both short-term measures to cope with emergency shortages, as well as long-term conservation actions that would beneficially reduce water loss and waste, require a procedural framework that would assist planners in evaluating a wide range of measures.

The information obtained from the survey suggests that there are limited types of conservation measures being implemented, compared to those that have been identified in the literature. Dziegielewski, et al. (1983) cite numerous references where listings can be obtained. Visits to twelve installations indicated either a lack of information regarding a broad range of potential water conservation measures or, when known, how to choose which would be the most effective and efficient. Two recent technical reports (Scholtz, et al., 1982, 1983) published by CERL,

provide review of water reduction domestic plumbing fixtures and irrigation control practices for consideration by installation water managers.

Additionally, there does not appear to be an exercised planning procedure in the selection of water conservation measures. Short-term emergency measures have generally achieved the goal of reduced water use during water shortages as shown in the responses of the survey participants, but it is not known whether the costs of implementation and effectiveness could have been lessened by the selection of alternative measures that may have also attained the desired reduction goal. Best judgment must prevail in an emergency by evaluating the applicable information on-hand. Planning for these emergencies, however, can occur prior to an emergency event and include an evaluation of a full range of alternatives. However, it was previously shown that at least 51 installations do not have water shortage contingency plans on hand. The Corps of Engineers Institute for Water Resources recently published guidelines for determining optimal strategies for water shortage mitigation in municipal and industrial water supplies (Dziegielewski, et al., 1983) which may be adaptable to the water planning needs for military installations.

Both long-term and contingent water conservation considerations should be required in the evaluation of the adequacy of existing installation water supplies and the actions needed to address future water needs. The need for new supplies and water system expansion must be assessed in light of the merits of demand reduction practices, which offer the potential for more efficient utilization of existing supplies

(Baumann, et al., 1980). There is little guidance to support a conclusion that evaluation procedures are available to installation planners to accomplish thorough water supply planning.

## Water Service Operation and System Maintenance Costs

The NDI study warned that water service could be expected to incur higher expenditures to produce on-post, as well as to reimburse local communities for the costs in providing water to Army posts. Using the cost data of the Redbooks for Fiscal Years 1975 through 1981, an analysis was undertaken to determine if costs have been rising in both operations and maintenance outlays. Fiscal year 1981 cost data was further analyzed to determine the presence and extent of relationships with patterns of water use, mission orientation, and sources of water supply.

### An Overview of Installation Water Costs

The Redbook data segregates water costs into two categories: operational (water service costs) and maintenance and repair (water system costs). Operational costs comprise purchased water and the operation of water treatment plants, including pumping at treatment and at source pumping plants. Maintenance and repair costs refer to the maintenance and repair of sources of water supply, water distribution systems, treatment and filtration plants, equipment for pumping and the storage of water. Capital expenditures for water system expansion or major component replacement are not given in the Redbook.

In order to measure recent patterns, 81 installations were identified that had continuous data reported throughout the seven years of records. Unit costs for total operations are computed by dividing the total annual cost for water service by the total annual quantity of water given in thousand gallon units to arrive at a unit cost in dollars per thousand gallons. Unit maintenance costs were derived similarly by dividing total annual maintenance and repair costs for water systems by the total annual quantity of water. This procedure also enables the unit costs for each category to be summed to provide a perspective of total costs for these two categories. Annual unit costs represent the average of the unit costs of the 81 installations (Table 17). Average costs are shown in both nominal (current) and 1983 dollars. The constant dollar figures were obtained by inflating current dollar data according to changes in the Gross National Product implicit price deflator. This procedure approximates the effect of cost changes on the total economy and has been used similarly by Boland (1983b) for describing water utility cost time trends.

Nominal costs for both operation and maintenance and repair increased respectively at the average rates of 15.9 percent and 18.9 percent per year. Inflation, during this period would tend to partially explain an increase; however, these average percentages exceed average inflationary rates for the same period. The constant dollar pattern, with the effects of inflation removed shows that operational costs are still increasing at an average annual rate of 4.60 percent. Maintenance and repair costs are growing annually at 6.48 percent on the average in 1983 dollars. Total average costs for the summed categories are also rising at a 5.45 percent average annual rate.

TABLE 17

AVERAGE OPERATION AND WATER SYSTEM MAINTENANCE AND REPAIR COSTS FOR 81 INSTALLATIONS IN CURRENT AND 1983 DOLLARS ($/Thousand Gallons Produced)

| Fiscal Year | Water Service Operating Expense | Water System Maintenance and Repair Expense | Total Expenditure |
|---|---|---|---|
| Current Dollars: | | | |
| 1975 | 0.233 | 0.194 | 0.427 |
| 1976 | 0.289 | 0.244 | 0.533 |
| 1977 | 0.293 | 0.285 | 0.578 |
| 1978 | 0.313 | 0.327 | 0.640 |
| 1979 | 0.384 | 0.338 | 0.722 |
| 1980 | 0.416 | 0.301 | 0.717 |
| 1981 | 0.492 | 0.451 | 0.943 |
| 1983 Dollars*: | | | |
| 1975 | 0.413 | 0.344 | 0.757 |
| 1976 | 0.484 | 0.409 | 0.893 |
| 1977 | 0.461 | 0.449 | 0.910 |
| 1978 | 0.457 | 0.478 | 0.935 |
| 1979 | 0.512 | 0.451 | 0.963 |
| 1980 | 0.506 | 0.366 | 0.872 |
| 1981 | 0.546 | 0.500 | 1.046 |

*Current dollar values inflated by Gross National Product fixed weight implicit price deflator (Council of Economic Advisors, 1984, p. 226).

(Source: Based on raw data from the Redbook, Office of the Chief of Engineers, 1982, 1981a, 1980, 1979, 1978, 1977, and 1976 for 81 Army fixed installations located in the contiguous United States.)

Trend Analysis of Combined Average Costs

To improve the mean estimate of the observed increase in total average costs, a bivariate regression analysis was conducted. Total unit costs for each year was designated as the dependent variable and time, measured in yearly increments, was tested as the independent variable. The results are expressed in the following model:

$$AC = .785 + 0.0314\ (t)$$

where AC represents the total combined average expenditure per thousand gallons of water in constant dollars as shown in Table 17. The regression slope of 0.0314 represents the annual increase in constant dollars for the seven-year period. The intercept value, or constant, is shown as $.78 per thousand gallons and time in years is represented by t. The coefficient was statistically significant at the 0.045 level, with a t-statistic of 2.655. The F Ratio was 7.047 and the Standard error measured 0.062. The correlation coefficient (r) was strong at 0.765. Total average costs in constant dollars increased at the rate of 3.1 percent per year during these seven years.

Although the data base represents a short time period, constant costs have risen consistently for total expenditures. Rising real costs signal needs for larger budget requirements to cover expenditures. A continuation of this pattern would give credence to the expected rising cost pressures related to installation water utilities and correspond with patterns visible in the civilian water industry. Master metering of all utilities in family housing areas has been recently directed by the Office of the Chief of Engineers (1983) with a completion goal for

master water meters by 1989. Perhaps cost pressures are already being exerted and this analysis of recent cost patterns would appear to substantiate their influence.

In a recent assessment of water utility financial practices, Boland (1983b) indicates that there is generally a lack of information regarding time trends in water utilities. Sampled utilities from periodic national surveys conducted by either the Environmental Protection Agency or the American Water Works Association exhibit different utilities and are not suitable for time trend analyses. Positive economies of scale, particularly among utilities producing relatively large quantities of water, would suggest decreasing average costs over time, but increasing incremental costs for major component repair and replacement could reverse this condition. It is likely that installation maintenance and repair costs for systems approaching the end of their expected economic life will grow in the near future and continue to influence time trends in an increasing direction.

Unit average costs are further examined in the sections that follow to determine patterns across all installations in the study area. Average costs for water service operation during Fiscal Year 1981 are analyzed to determine significant relationships with selected variables.

## Average Unit Operating Costs and Average Day Water Use

Unit costs for water service operation in FY 81 ranged from $.03 per thousand gallons ($/k-gal) at Natick Development Center, Massachusetts to $2.87 per thousand gallons at Tooele Army Depot, Utah.

The median value for all 90 installations was \$.53 per thousand gallons with a standard deviation of \$.51 (\$/k-gal). A joint frequency analysis was conducted to test the hypothesis that above average unit costs are more likely to occur on installations with below average daily water use throughout the population. This reasoning appears plausible for at least two motives: installations with above average water use may be purchasing water at preferential wholesale rates with decreasing block rate structures or may be producing their own municipal water under favorable economies of mass production. Average unit costs were divided about the population mean and assessed against the distribution of average daily water use, also separated at the population mean for this independent variable. The analysis resulted in a statistically significant relationship between average unit operating costs and average daily water use (Table 18a). Moreover, the correlation coefficient was negative in sign and highly significant indicating that posts using water quantities above the population mean are likely to have unit operating costs below the average for the 90 installations.

## Operating Cost Relationship with Mission Orientation

If lower than average unit costs for water service operation are characteristic of higher than average daily water use, it would seem reasonable that the lower costs would also prevail on installations assigned to FORSCOM and TRADOC. It was previously determined that stations aligned with troop unit readiness and training tended to be above average daily water users. An analysis of average unit costs with

TABLE 18

SELECTED RELATIONSHIPS WITH AVERAGE UNIT OPERATING COSTS

a. Average Unit Operating Costs and Average Daily Water Use

| Average Operating Costs | Average Daily Water Use | | | | | |
|---|---|---|---|---|---|---|
| | Below Average | | Above Average | | Totals | |
| | N* | % | N | % | N | % |
| Below the mean | 30 | 51.7 | 28 | 48.3 | 58 | 64.4 |
| Above the mean | 30 | 93.8 | 2 | 6.3 | 32 | 35.6 |
| TOTALS | 60 | 66.7 | 30 | 33.3 | 90 | 100.0 |

*Number of Responses
Chi-square = 16.390 with 1 d.f.
Significance = 0.0001
R = -0.427
Significance = 0.0001

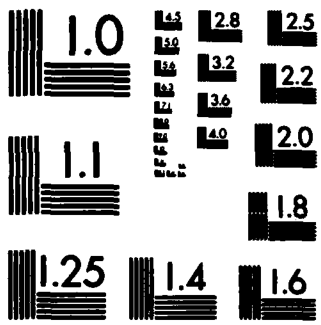
b. Average Unit Operating Costs and Mission Orientation

| Average Operating Costs | Mission Orientation | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FORSCOM | | TRADOC | | DARCOM | | ALL OTHERS | | TOTALS | |
| | N* | % | N | % | N | % | N | % | N | % |
| Below the mean | 17 | 29.3 | 16 | 27.6 | 21 | 36.2 | 4 | 6.9 | 58 | 64.4 |
| Above the mean | 5 | 15.6 | 5 | 15.6 | 14 | 43.8 | 8 | 25.0 | 32 | 35.6 |
| TOTALS | 22 | 24.4 | 21 | 23.3 | 35 | 38.9 | 12 | 13.3 | 90 | 100.0 |

*Number of responses
Chi-square = 8.215 with 3.d.f.
Significance = 0.0418

AD-A145 739 FORECASTING WATER USE ON FIXED ARMY INSTALLATIONS WITHIN THE CONTIGUOUS UNITED STATES(U) ARMY MILITARY PERSONNEL CENTER ALEXANDRIA VA J F LANGOWSKI 22 JUN 84 2/3

UNCLASSIFIED F/G 13/2 NL




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

mission orientation failed to reject the null hypothesis that this systematic relationship was not evident within the study area (Table 18b). Both FORSCOM and TRADOC installations exhibit more installations than expected having below average operating costs and, conversely, DARCOM and the "All Other" grouping of the remaining Major Commands have a greater than expected number of installations with higher than average costs. The relationship between average unit operating costs, measured by Chi-square, was significant below the 0.05 criterion level.

## Average Unit Operating Costs and Sources of Water Supply

It is reasonable to hypothesize that installations providing water service from a single source of supply are likely to have higher than average unit costs for water service operation. They may be constrained to a single source and supplemental sources may be physically or economically prohibitive. If average costs are indeed increasing concurrently, these stations would generally reflect higher costs than the population average. On the other hand, posts with multiple sources of water have expanded options and can mix source withdrawals to coincide with a least cost solution.

A two-way frequency analysis confirmed a statistically significant relationship between average unit operating costs and water source complexity (Table 19). The correlation coefficient ($r = -0.282$) also indicates the direction of the relationship consistent with the formulated hypothesis.

TABLE 19

AVERAGE UNIT OPERATING COSTS AND SOURCES OF WATER SUPPLY

| Operating Costs | Sources of Water: Single N* | % | Multiple N | % | Totals N | % |
|---|---|---|---|---|---|---|
| Below the mean | 21 | 36.2 | 37 | 63.8 | 58 | 64.4 |
| Above the mean | 21 | 65.6 | 11 | 34.4 | 32 | 35.6 |
| TOTAL | 42 | 46.7 | 48 | 53.5 | 90 | 100.0 |

*Number of responses
Chi-square = 7.171 with 1 d.f
Significance = 0.0074
r = -0.282
Significance = 0.0035

## Summary of Water Planning and Related Patterns of Water Use

Average daily water use during Fiscal Year 1981 was assessed to determine the characteristics of above average users versus below average users. By dividing the 90 installations at the mean population value of 1.8 million gallons per day, it was statistically determined that installations requiring daily quantities of water above this demarcation value were generally oriented with missions of operational and deployment readiness or intensive soldier training, had multiple sources of water supply, and contained above average total gross floor area for all buildings. Installations below the population mean for average daily water use were usually aligned with logistical support or material development missions, had one source of water supply, and were smaller in size regarding total building floor area.

Installation visits were made to posts representing these various mission functions to gain insights into how these characteristics impacted upon water planning and preparedness. In most cases, installation water utility managers appeared confident that water needs for the future could be adequately sustained with existing water sources and water system capabilities. There appeared to be little incentives to evaluate the potential benefits of conservation measures, unless a proposed measure suggested a concurrent dollar savings in energy consumption reduction.

Yet, the results of a mail survey, in which 86 installations responded, indicated that more than one-third did not know what quantities of water would be needed to support Fiscal Year 1990

requirements. Even among those posts which adjudged a general direction in future water needs (increase, decrease, or remain about the same in FY 1983 levels), only about one-fourth of the reporting stations have apparently evaluated water needs for the future using a planning method that goes beyond judgmental planning. The 22 water use forecasts that have been done, however, are based on a per capita or adjusted per capita approach, which does not facilitate the evaluation of water conservation measures.

Indicators of water planning were assessed and included the status of water shortage contingency plans and water conservation programs. A summary tabulation of the responses by Major Command is provided in Appendix B. Documented contingency plans are more likely to be found on FORSCOM and TRADOC installations, while no plans predominate among DARCOM stations, where single sources of water supply prevail. The majority of installations (59%) indicated that plans were not on-hand and reflects a need to increase planning emphasis in this area.

There is no water conservation policy disseminated throughout Army installations and as a result, 55 (64%) of the surveyed installations indicate that they have not implemented a water conservation program within the past five years. Moreover, the types of conservation measures being executed are limited primarily to irrigation restrictions and reduced flow plumbing fixtures, and in most instances, the benefit or costs of having implemented these measures have not been quantified. It would appear that a mandated water conservation policy would provide a stimulus to broaden this water planning effort; however, procedural guidelines are needed to assist installation planners in evaluating

potentially adaptable and socially acceptable conservation actions.

An additional incentive is the recognition that total average costs for water service operation and water system maintenance and repair have been increasing significantly in constant dollars during the period 1975 through 1981. These costs are likely to continue to rise, particularly on posts where aging system components will need replacement. Capacity requirements will have to be reevaluated in light of demand reduction opportunities offered by water conservation programs. Within the study area, FORSCOM and TRADOC installations reflect typically lower than the mean for average operating costs. DA COM and the remaining grouped Major Commands generally have exhibited higher than average costs for water service operation, attributed in part to their characteristic single source of water supply.

The first objective of this study was to identify and report on available information which supports or rejects the conclusions of the NDI study regarding increasing water service operation and maintenance and repair costs and inadequate water supply planning emphasis within the study area. This analysis attests that water service planning within the study area is inadequate in three areas: forecasting, water shortage contingency planning, and procedural assessment of potential water conservation measures. Additionally, recent patterns in average water utility operation, maintenance and repair costs indicate that they are increasing annually in real dollars, pointing to mounting pressures for larger budget allocations for these activities. Improved planning procedures would provide a platform for developing ways to curb these rising costs.

# CHAPTER IV

## ANALYSIS OF CURRENT WATER USE ESTIMATION PROCEDURES

Per capita water usage values have been purposely avoided in the analysis thus far and warrant an explanation. Per capita computation would require the use of the effective population data entered for each installation in the Redbook and there is reason to suspect that the values for effective population are misleading. It was observed during installation visits that water utility managers and planners rarely referred to water use in per capita measures. They frequently commented that per capita measures, if used, would be subject to large changes, depending upon how the census was conducted and whether Reserve or Army National Guard units were present for annual field training. Surges in population caused by these training cycles, as well as summer seasonal water requirements, would affect per capita water use values. Furthermore, the effective population is not consistently computed by the same staff agency on every installation and was not being calculated by the Directorate of Engineering and Housing. These observations raised questions regarding measurement procedures and are identified and examined herein.

## Current Procedures for Estimating Average Daily Water Requirements

An effective population is computed based upon the military dependent and civilian populations of an installation. The effective population is calculated on a monthly basis by averaging the sum of daily counts of resident military and civilian personnel and their family members and one-third of all non-residents. The annual values represent the average of the sum of the previous twelve month averages and are given in the Redbook.

Moreover, the effective population is a key determinant in the existing estimation procedures for installation average water requirements. This effective population is multiplied by a multi-purpose capacity factor to yield a design population which is then used to determine the required capacity of the supply works. The required daily demand is the product of the design population and a per capita water allowance of 150 gallons per day, plus any special industrial requirements and irrigation demands (Figure 2).

### Effective Population Errors

There are two major problems in using effective population in computing installation water use. First, this procedure assumes that non-residents account for one-third of the water of residents and that a bachelor soldier living on post has identical per capita water use as a resident family member. Metering studies done by the Army's Construction Engineering Research Laboratory (Bandy and Scholtze, 1982, p. 50) at Fort

<u>EFFECTIVE POPULATION</u>:

RESIDENT MILITARY AND CIVILIAN PERSONNEL

FAMILY MEMBERS OF THE ABOVE

NON-RESIDENTS
(SOLDIERS, FAMILY MEMBERS, CIVILIANS
WHO COMMUTE TO THE INSTALLATION)

$$\text{EFFECTIVE POPULATION} = \frac{\text{NONRESIDENT POPULATION}}{3} + \text{RESIDENT POPULATION}$$

<u>DESIGN POPULATION</u>:

[EFFECTIVE POPULATION] X [CAPACITY FACTOR]

<u>REQUIRED DOMESTIC DEMAND</u>:

[DESIGN POPULATION] X [PER CAPITA DOMESTIC WATER ALLOWANCE]

<u>REQUIRED DAILY DEMAND</u>:

[REQUIRED DOMESTIC DEMAND] + [SPECIAL PURPOSE WATER USES]

(INCLUDES INDUSTRIAL, AIRCRAFT-WASH, IRRIGATION
AIR CONDITIONING OR OTHER DEMANDS)

Figure 2

Current Procedures for Estimating Required Daily Water Service

(Source: U.S. Department of the Army, 1979a)

Carson, Colorado revealed that civilian non-resident use is more nearly one-ninth than one-third of the allotted 150 gallons per capita per day (gpcd) allowance. Soldiers living in troop housing were metered at Fort Carson and Matherly, et al., (1978) found that water usage on a per capita per day basis ranged from 29 to 77 gallons during the period April through June 1977. The proportional weighting scheme for effective population on this installation during this time would more likely be approximately 9:3:1 for residents, bachelor soldiers and civilian non-residents, in that order. An inaccurate weighting scheme applied as a general procedure to all installations results in a corresponding inaccurate estimation of the water service population. Obviously, per capita water usage values computed from erroneous population estimations would be procedurally unacceptable.

The second problem is the current procedure for estimating an annual representative value for average effective population as it is shown for each installation in the Redbook. Averaging monthly average effective population values (assuming that they are representative values) to arrive at an annual value for estimating per capita water service also leads to error. This problem can be seen by referring to the entries of Table 20 which shows actual monthly data obtained from an earlier study done at Fort Chaffee, Arkansas (Muir and Associates, 1979).

The annual average daily values for delivered water, effective population and per capita consumption have been calculated and are shown in the table. Per capita consumption values are not given in the Redbook. Only the total annual water service and annual average daily effective population figures are shown. Computing a value based on

TABLE 20

WATER DATA FOR FORT CHAFFEE FY 1978

| Month | Total Delivered Water K-gal | Average Daily Effective Population per month | Average Daily Per Capita Consumption gpcd |
|---|---|---|---|
| Oct 77 | 2,535 | 298 | 284 |
| Nov 77 | 2,049 | 253 | 270 |
| Dec 77 | 3,795 | 207 | 611 |
| Jan 78 | 11,141 | 161 | 2,307 |
| Feb 78 | 12,248 | 257 | 1,589 |
| Mar 78 | 9,131 | 312 | 976 |
| Apr 78 | 10,399 | 1,213 | 286 |
| May 78 | 13,991 | 1,397 | 334 |
| Jun 78 | 21,369 | 10,276 | 69 |
| Jul 78 | 22,730 | 13,502 | 56 |
| Aug 78 | 10,880 | 5,000 | 73 |
| Sep 78 | 5,130 | 238 | 718 |
| Annual Total | 120,268 | --- | --- |
| Annual Average Daily Values | 329,501 gallons | 2,760 | 631 gpcd |

(Source: Raw Data from Robert G. Muir and Associates, 1979, p. 1-8)

annual average daily water service (total divided by 356 days) and annual average daily effective population results in a quite different estimation of per capita water service. This is exemplified by comparing the per capita values derived from the two methods:

$$\sum_{N}^{N=12} \frac{\text{Monthly Average Daily Per Capita Water Usage}}{12} = 631 \text{ gpcd} \qquad (1)$$

$$\frac{\text{Annual Average Daily Delivered Water}}{\text{Annual Average Daily Effective Population}} = \frac{329{,}501}{2760} = 119 \text{ gcpd} \qquad (2)$$

Equation (2) depicts the problem of successive averaging of daily effective population figures to arrive at a monthly average daily value, then averaging the results to obtain an annual average daily value. In this example, it results in a gross underestimation of average daily per capita water usage. Moreover, the 631 gpcd value does not reflect the broad range of monthly per capita values, which in this case, varies from a low of 56 gcd (13,502 effective population) to a high of 2307 gcd (161 effective population). This wide fluctuation in monthly population values would indeed be a rarity among civilian communities but is a frequently found pattern on Army installations that serve as a periodic training site for Army Reserve and National Guard units.

A Test of Current Estimating Procedures

As a further test to determine the reliability of the FY 1981 Redbook effective population data, the average daily per capita water use

values were calculated for each of the 90 installations by dividing a computed average daily water use quantity for the given installation by the effective population value. These values for 90 installations were used in a bivariate regression analysis with effective population as the dependent variable. The mean value for average daily per capita water use indicator was 242.04 gpcd with a standard deviation of the mean at 349.67 gpcd and a standard error of the mean at 36.86 gpcd.

The results of the analysis are as follows:

| | | | | |
|---|---|---|---|---|
| Average daily per capita water Requirements | = | 324.78 (6.778) | - 0.006 (effective population (-2.591) | (1) |

The values of the t-statistic are given in parentheses and were both significant below the 0.02 level. However, the coefficient of determination ($R^2$) was only 0.071 and the standard error of the estimate was 338.96 gpcd. The capability of this model to predict is obviously unacceptable. Installations with small populations would generally be over-estimated. Additionally, the mean value of the estimated average day per capita water use is nearly one-and-a-half times as large as the national average of 166.74 gpcd determined in a 1981 survey of water utilities by the American Water Works Association (1981). The negative sign of the coefficient suggests that per capita water use is inversely related to the size of the effective population. The larger the effective population, the lower the value for per capita water use.

To adjust for this bias, the designers of the current procedures

for estimating average daily water use apparently "normalized" all per capita consumption values to 150 gpcd and introduced an adjustment factor, known as the capacity factor, into their estimating equation. Bandy and Scholze (1982) investigated the derivation of this factor and its functional purpose. The capacity factor varies inversely with the magnitude of the population in the service area and is intended to provide an allowance for population increase, variations in water demand, uncertainties as to actual water requirements and for unusual peak demands. An effective population of 5,000 or less would have a capacity factor of 1.5, while an installation with 50,000 or more persons would have a capacity factor value of 1.0.

Because the current procedures for estimating average daily water use are linked explicitly to effective population, it is reasonable to conclude that approximations of average daily water use would also be suspect. To test this conclusion, the procedures shown in Figure 3 were followed and calculations were made of the expected average daily water use for the 90 installations by multiplying the effective population values in the Fiscal Year 1981 Redbook by the appropriate capacity factor and a prescribed per capita daily allowance of 150 gallons. Special purpose quantities of water are not known for each installation and were assumed to be zero during the test. Because of this limitation, it was reasonable to expect that the estimates would be less than the actual average daily water use in the Redbook data base. The Redbook data for water use is an aggregate measure and encompasses all water delivered throughout each installation.

A comparison was then made between the actual and estimated average

daily water use, anticipating that the latter value would be smaller than the actual value because special purpose water was not included in the computation. It was determined that 57 out of the 90 installations (63%) had expected average uses greater than actual, indicating substantial overestimation (Figure 3).

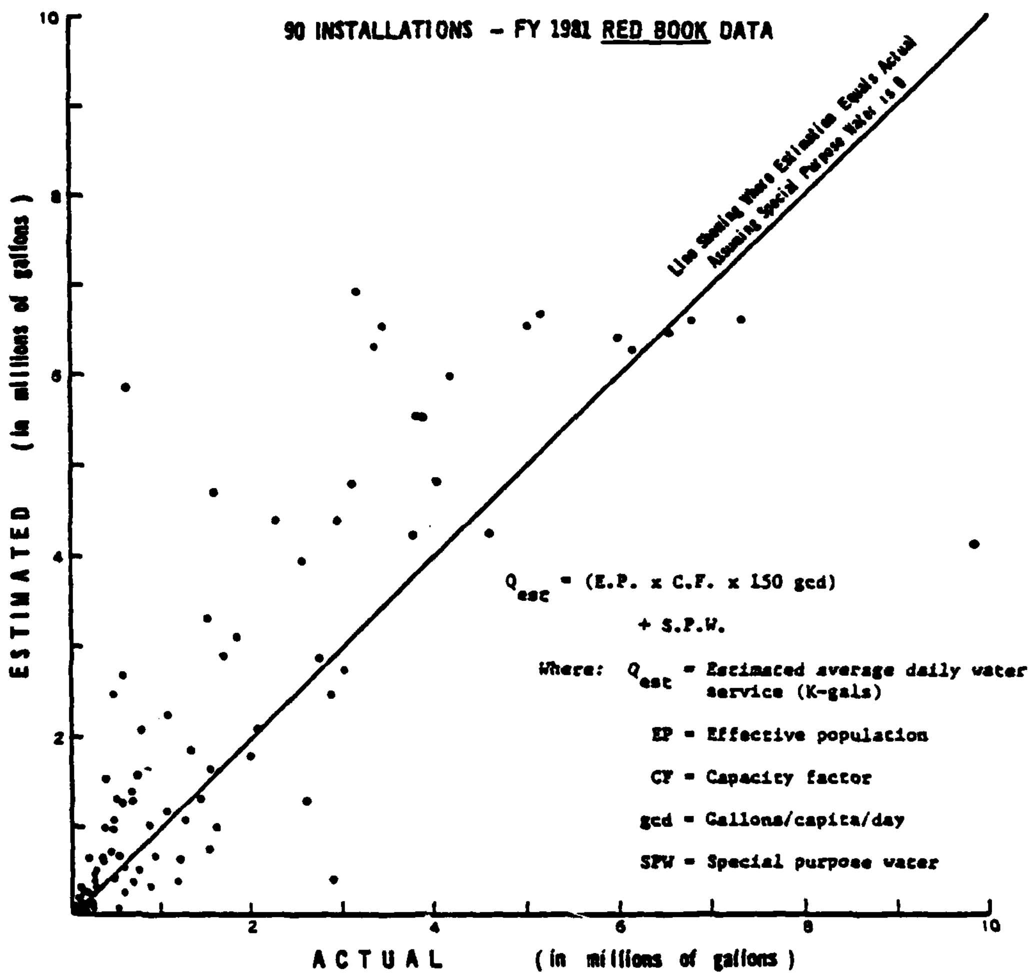
An analysis of variance of the predicted and actual values for average day water use was conducted to determine the coefficient of determination ($R^2$) and the standard error (SEE) of the estimate. The $R^2$ value was 0.564 and the SEE was 1.374 million gallons per day.

It is not possible to adjust the range of error in the estimated values without knowing quantities of water for special purposes; however, there is a lack of data because of the absence of meters for these activities. Moreover, for those installations already being overestimated, added special purpose water would further exaggerate average daily water use approximations.

Collectively, the indicators observed from this assessment are sufficient to conclude that attempts to predict water usage using any form of effective population as it is presently calculated and shown in the Redbook data base, would result in substantial error. There are a variety of procedures being practiced throughout the water industry and are briefly overviewed in the following section. The methods are examined for application to Army installations.

## Water Use Forecasting Methods in Civilian Communities

Water demand or requirement forecasting methods have improved




COMPARISON OF ACTUAL VS. ESTIMATED AVERAGE DAILY WATER SERVICE APPLYING CURRENT COMPUTATIONAL GUIDELINES

Figure 3

sustantially in the past 20 years. One way of categorizing these techniques is to separate them by the complexity of the variables extended into the model specifications. Single and multiple coefficient methods are discussed and selected examples are critiqued from the perspective of compatibility with the existing Army data base.

## Single Coefficient Methods

Single coefficient methods of estimating water use employ a single explanatory variable in the prediction model. Hansen, et al. (1979) estimated average daily per capita withdrawals based on historic population and consumption data for 50 Utah municipalities. The population ranged from 345 to 169,971, with only one community exceeding 69,000 people. This range is similar to the population profile for Army installations; however, Utah communities are not likely to undergo large surges or drops in population levels which often occur on Army installations. Shaake and Major (1972) developed a computerized model which estimates future gross rural domestic water use based on rural population projections, multiplied by a per capita rural domestic use coefficient. This procedure, however, estimates a specific sector of water use, rural domestic water, and would not be applicable to aggregate average daily water use, the current standard water use measure prescribed by Army guidelines.

Other single coefficient methods, such as per customer and per connection models, require data that would satisfy empirical analysis using these model forms; however, this data is not readily identifiable

on Army installations. Unit use coefficient methods are frequently used to estimate commercial water use (Thompson, et al., 1976; McCuen, et al., 1975) and industrial water use (Rees, 1969; Shaake and Major, 1972; Hittman Associates, Inc., 1969). In general, water use is forecast as a function of the number of industrial employees or number of households within the framework of a disaggregate forecast. Application on Army installations would require data on water use for commercial and industrial activities. Here again, this data is not separable from total water service measurements.

The Forecasting Assessment provides an evaluation of single coefficient methods. The per capita approach, although capable of providing some planning information, has numerous limitations. Water use is assumed to continuously vary proportionately with population, from the past and into the future. The per capita approach, produces an aggregate prediction and excludes many of the factors known to influence water use. Moreover, it does not facilitate the evaluation of water conservation. Fundamentally, the population estimation must be accurate to achieve even the rough approximation that this method offers. The Army procedure for calculating effective population fails to meet this minimum criteria.

## Multiple Coefficient Methods

Multiple coefficient methods use two or more explanatory variables as a mathematical function of future water use. The variables are chosen because of their past correlation to water use and the functional

form is selected to provide an acceptable fit to historic data. Water use models can be estimated usually by means of regression analysis from cross-sectional data representing simultaneous observations of water use and explanatory variables at a number of locations during a single time period (Boland, et al., 1983). The Redbook data for Fiscal Year 1981 exhibits these characteristics and provide the basis for testing a water requirements model.

Studies have shown multiple coefficient requirement models perform well in predicting aggregate and sectoral water use. Burke (1970) estimated the parameters of multivariate models which incorporated 17 explanatory variables reflecting environmental, social and economic factors for forecasting aggregate requirements for municipal water. He developed separate regression models for 19 geographic regions, representing cross-sectional data from 488 cities. Similarly, Frnka (1979) applied cross-sectional data from all counties in Mississippi to estimate variable coefficients.

Studies were sought to determine if, among tested explanatory variables, building square footage and acreage were used in the prediction of water use. A number of published reports show significant relationships between water use and area variables. Burke's study (1970) incorporated land area in square miles into his model and found it to be a significant predictor in approximately half of the regions studied. Kim and McCuen (1979) found that gross store area represented an employee factor in their model of commercial water use. Other investigators using multiple coefficient demand models (include price variables of water and income) have recognized the size of residential

lots (Howe and Lineaweaver, 1967) as an important explanatory variable in forecasting residential water demand. Sonnen and Evenson (1979) used building areas and acres in a given land use category together with other variables to calculate total average monthly water use.

Romm (1977) argues that land use projections are more reliable than population projections for the determination of future water requirements. In his disaggregated projection for Santa Clara Valley Water district, residential, industrial and agricultural use are estimated as a function of subarea location, land area in acres, expected land use and other inputs based upon a master plan for the region.

In many ways, his conceptualization is analogous to the hypothesis that water use on Army installations can be explained by grouped building areas. A major difference between these approaches is the level of data representing land use activities. In this study, functional building gross area in square feet, rather than functional land areas, are analyzed. It is unlikely that a civilian community could generate the comprehensive categorized building area data base that is maintained as standard procedure on Army installations. It would require an extraordinary collection effort that would extend beyond extracting data from county clerk or assessor records in order to account for every building within the bounds of the community. Because of other more readily available data for explanatory variables, this kind of data base has not been examined by other investigators. On the other hand, the Redbook data base is confined to its present contents and additions to it would incur costs not only in terms of time and

money, but amendment to current governing regulations for the preparation of the input technical reports. Although more detailed data, such as individual building areas and monthly quantities of water use are maintained at the installation level, it would be necessary to obtain permission for its release through the military chain of command.

In this study, categorized total building areas are examined for variance differences in order to sum them into new composite variables that represent independent sectors of water use. Improved ground acreage and evapotranspiration are also empirically tested in the conceptualized model. The details of this analysis are presented in Chapter V.

## Summary

The second study objective was to evaluate current Army procedures for estimating average daily water demand and demonstrate predictive ability. The measure of effective population, a key parameter in these procedures, is suspicious due to the questionable weights applied to resident and non-resident groupings. The data representing effective population in the Redbook cannot be used to determine per capita average daily water use because of errors in the method by which it is computed. The current procedures for estimating average daily water use were demonstrated and compared to actual water use values for the 90 installations in the study area. The results show that estimation is inaccurate and predictions of future water requirements using this procedure would be unacceptable.

## CHAPTER V

## DATA STRUCTURE ANALYSIS AND MODEL DEVELOPMENT

### Introduction

The existing Army procedural guidelines for estimating average daily installation water requirements were assessed in the preceding chapter and were found to be wanting primarily because the measurement of effective population was inaccurate. An alternative approach is examined in this chapter which not only improves estimation, but is also acceptable as a prediction tool for forecasting future peacetime water requirements for the installations in the study area. The model is developed from an analysis of the structure of cross-sectional data representing the gross square footage of categorized buildings on 90 installations. Water usage sectors are identified and further tested to determine statistical relationships with average daily water use. The results of these tests and subsequent multivariate regression procedures are presented and interpreted.

### The Conceptualized Model

The generalized model to be utilized as a framework for this study

takes the following form:

$$Q = f\ (S_1,\ S_2\ .\ .\ .\ S_n,\ MD) \tag{4}$$

where:

$Q_{ad}$ = average daily installation water service in 1000 gallons (k-gals)

and is a function (f) of:

$S_1$ ... $S_n$ = independent variables related to allocated building gross floor area in 1000 square feet (k-sq ft) and representing sectors of water use.

MD = summer moisture deficit factor for total improved grounds area in acres, further defined as:

$$MD = TOIMPG\ (w_r - 0.6r_s) \tag{5}$$

where:

TOIMPG = total improved ground acreage per installation

$w_r$ = summer average potential evapotranspiration rate

$r_s$ = average summer precipitation rate

Each sector is composed of one or more categories of buildings which will be identified through an analysis of the data structure representing the gross square footage of each category. There are twelve categories of building areas that encompass every building on any post where water use can occur. The moisture deficit factor accounts for outdoor irrigation or dust control water use and embodies the land area where water is spent for this purpose. Conceptually, therefore, the model includes all areas where water is delivered and utilized on a given installation.

The sectors may be considered initially to represent the commonly

recognized residential, commercial, industrial and institutional water use sectors. However, the special considerations that may affect water use patterns discussed in Chapter II may affect the final composition as well as nonmenclature for installation sectors.

It is critical in this analysis that all twelve categories be included in the pending sectoral constructs to assimilate the total post real property where water use occurs. Exclusion of a single category would suggest that it has no relationship to installation water service but there is no evidence to support such conclusions. Additionally, category rejection would weaken the combined sector array and imply incomplete final model specification. Although the model developed herein is intended to be used for prediction, it must actually provide for a reasonable explanation of water service as a complete composite of various sectors of water-using activities.

## Building Categories and Moisture Deficit Factor

### Identification and General Description

Categories of buildings range from family housing structures to research and development buildings with all areas measured in thousand square feet units and the category contents are non-overlapping. The Redbook provides gross floor area measurements of every building category on each installation in thousands of square feet. This accounting is based on a uniform construction category coding system, established by Army Regulation and applies to every installation in the

Army. The general categories of building areas are shown in Table 21 as independent variables 1 through 12. Because of the uniform coding system, the Army is able to keep an accurate inventory and control of all facilities in a compatible manner. Each category is independent of all others regarding the content of the types of buildings it contains. A discussion of each category and its expected effect on water service follows.

## Family Housing

This category represents all buildings as family quarters, including attached private garages and detached appurtenant structures such as garages, adjacent storage sheds, laundry rooms and incinerators. The types of housing include single family residences and multiple family permanent dwellings. Water service is expected to increase with added buildings in this category that is typified by domestic water uses.

## Bachelor Soldier Quarters

Housing for unaccompanied personnel (without on-station family) is provided by barracks, dormitories and other similar facilities with or without dining (kitchen) facilities. Detached dining facilities where soldiers and civilians regularly have their meals as a group and day rooms (lounge and game rooms) are also included in this category. Water-using activities are personal hygienic in nature, but would also

TABLE 21

LIST OF VARIABLES AND THEIR DESIGNATIONS

| No. | Symbol | Variable Definition | Unit |
|---|---|---|---|
| | Dependent Variable: | | |
| 1 | $Q_{ad}$ | Average daily water service | k-gal |
| | Independent Variable: | | |
| 1 | FAMBLD | Family housing gross floor area | k-sq ft |
| 2 | BACBLD | Bachelor housing gross floor area | k-sq ft |
| 3 | TRABLD | Training buildings gross floor area | |
| 4 | COMBLD | Community buildings gross floor area | k-sq ft |
| 5 | MEDBLD | Medical buildings gross floor area | k-sq ft |
| 6 | OPSBLD | Operations buildings gross floor area | k-sq ft |
| 7 | MNTBLD | Maintenance and production buildings gross floor area | k-sq ft |
| 8 | STOBLD | Storage buildings gross floor area | k-sq ft |
| 9 | RDTBLD | Research development and test buildings gross floor area | k-sq ft |
| 10 | UTPBLD | Utility plants gross floor area | k-sq ft |
| 11 | ADMBLD | Administration buildings gross floor area | k-sq ft |
| 12 | OTHBLD | Other buildings gross floor area | k-sq ft |
| 13 | MDEFICIT | Average moisture deficit factor | in./acres/ summer |

satisfy water requirements associated with large mess halls, comparable to commercial cafeterias of the same size. Here again water service would increase commensurate with an expansion of the facilities in this category. Laundry facilities (washing machines) are generally centrally located in dormitories for common use by building residents, who may prefer to use laundromats located elsewhere.

## Training

Classrooms and other special buildings in which instruction is given make up this category and would cover structures on training courses, ranges and maneuver areas. Water is required for drinking and sanitary purposes and the service to these buildings would increase as new structures are added or existing facilities expanded.

## Community Service

Buildings in this category provide for the support and service of installation personnel and their morale, welfare and indoor recreation needs. The types of structures within this category extend across a broad range of public and commercial support activities which suggest occurring water uses. Facilities for the support of the community take into account fire stations, guard and police station, bus or ticket stations, post office, chapels, laundry and dry cleaning plant, bakery and nursery, and elementary and secondary schools for the family members of assigned Department of Defense personnel. Indoor athletic and

recreational activities and retail outlets are also embodied in this category. Typical establishments are bowling alleys, field houses, gymnasiums and indoor swimming pools; banks, service personnel clubs and open restaurants; theaters and auditoriums, recreational and entertainment workshops and craft centers; AAFES main and branch exchanges, concessions, gas stations; and Red Cross and YMCA centers. Water requirements for these activities would not be unlike those of a civilian community and would be greater as more structures are added to the installation real property inventory.

## Medical

These buildings support both in-patient and out-patient hospital and medical center support, as well as triage, clinical and medical dispensary facilities for soldiers and their families. Dental clinics and veterinary facilities are included but medical research, development and testing (RD&T) buildings are assigned to the RD&T building category. Water is used for patient services and medical hygienic and operational requirements and it is reasonably assumed that, generally, facilities with larger floor areas support greater numbers of patients and would need complementary increments of water to accommodate medical mission sustentation.

## Operations

This category of buildings is dominated by military mission-related

activities, such as communication structures for radio, radar, relay and telephone operational networks. Operational readiness facilities, such as alert hangars, operations, and fire and rescue stations at airfield and missile war-heading and launching structures, are typical examples. Reception station processing facilities are also assigned to this category. Water service to support these activities is assumed to be small, compared to other categories both in water quantity, as well as total category building area but would increase to correspond with building growth and new construction.

## Maintenance and Production

Maintenance activities encompass facilities and shops for the maintenance, repair and overhaul of all military equipment and installation real property. It also includes plants for the construction and assembly of classes of military supplies, to include ammunition. This category also reflects mission oriented activities and is likened to manufacturing establishments in civilian communities. Water use for industrial processing may be quite large depending upon the manufactured end product, such as ammunition. Water service and maintenance and production facilities are directly related and changes in the square footage areas of buildings can be assumed to be matched by complementary changes in water requirements in the same direction.

## Storage

Water service is minimal for activities which describe the buildings in this category. Water is used for custodial functions, if any, and to arm fire sprinkling systems. Ammunition storage structures and warehouses comprise the principal types of buildings in this category. It is assumed that activities represented by storage facilities exert a weak influence on water service and would not explain or predict major quantities of average daily water service. An increase in the total gross floor area of storage facilities on installations with dedicated depot missions is likely to raise water service requirements to support fire-fighting operations if all other water-using activities remained constant.

## Research Development and Test (RD&T)

These buildings are used directly in theoretical or applied research operations. Science laboratories related to basic research, such as chemistry, materials, medical, biological, sonic, physics and geophysics are contained in this category, as well as development and test facilities related to this research. Water service to support these activities is expected to be high, especially on installations exhibiting substantial building areas for RD&T.

## Utility Plants

Cold storage freeze and chilled water for air conditioning plants and cold and refrigerated warehouses are classified into the utility plant category. Buildings associated with electric power generation or transmission heating or powerplant generation equipment for temperature controlled water or pressure regulated steam, municipal sewage and industrial waste treatment and disposal structures, non-potable and potable water supply (wells), treatment and storage tanks are also included. Water is generally an integral component of the activities associated with these buildings and it is expected that the larger the gross floor area of this category, the greater the average daily water use required to satisfy the functions of the utility plant buildings.

## Administration

Buildings within this category include headquarters and office type buildings for civilian and military personnel administration, automatic data processing and technical libraries. Water is required for sanitary, custodial and fire extinguishing systems. Again, water service would tend to increase with increase in the gross floor area of administration buildings.

## Other

This category envelops all buildings not designated within the

previous eleven categories. Examples are limited because of the comprehensiveness of the other categories; however, museums and covered grandstands and bleachers have been identified as constituents. Water use is minimal and contributes to only a small fraction of average daily water use.

## Moisture Deficit

Installation water use may also be affected by the amount of sprinkling water applied to irrigable areas. A past study (Linaweaver, 1965) has shown that sprinkling patterns closely align with potential evapotranspiration when antecedent precipitation has been dissipated. Howe and Linaweaver (1967) defined this influence as summer potential evaporation in inches minus 60 percent of the summer precipitation in inches. Hittman Associates, Inc. (Volume II, 1969) incorporated this measure in the MAIN II System for forecasting municipal water requirements and determined values from interpolations of summer potential evapotranspiration and precipitation contour maps. This latter technique was used for this study and a complete listing of the data for this measure at each installation is provided in Appendix C.

Howe (1982) formulated a moisture deficit variable which he defined as the product of the outdoor irrigable area and the quantitative influence of the weather factor as defined above. The 0.6 constant applied to the average summer precipitation was further stipulated as the effective fraction of average summer rainfall penetrating to the vegetative root zone. This construct is identical to the independent

variable that is used in the water requirement model of this study. The outdoor irrigable area is represented by total improved grounds measured in acres.

## Statistical Analysis of the Data Structure

Because of the large number of independent building categories being analyzed, it was necessary to establish criteria to be used in selecting groups or individual categories to represent water service sectors, specified as the final explanatory variables in the conceptualized general model. Substantial high multicollinearity among the building category variables required a strategy for reduction to an acceptable level where regression coefficient estimates would not be adversely affected. The following sections describe the results of various statistical analyses applied in the preliminary stages of the model development.

### Linearity Characteristics

The first step in the data analysis was to examine the general statistics describing the distribution of the ninety installations for each building category and evaluate the linear relationship of each category variable with average daily water use ($Q_{ad}$). Three measures are associated with simple linear regression: the Pearson product moment correlation coefficient, its test of significance and the slope. The values of these measures are presented in Table 22 with other related

TABLE 22

STATISTICAL CHARACTERISTICS OF THE VARIABLES*

| Variable Code | High Value | Low Value | Mean | Standard Deviation | Correlation Coefficient** | Correlation Significance | Bivariate Regression Slope | Slope Significance*** |
|---|---|---|---|---|---|---|---|---|
| $Q_{ad}$ | 9847 | 11 | 1813 | 2080 | -- | -- | -- | -- |
| FAMBLD | 8294 | 0 | 1444 | 2019 | .838 | .0001 | .863 | .0001 |
| BACBLD | 7704 | 0 | 1347 | 1885 | .772 | .0001 | .852 | .0001 |
| TRABLD | 2574 | 0 | 446 | 566 | .594 | .001 | 2.183 | .0001 |
| COMBLD | 1937 | 0 | 481 | 501 | .809 | .0001 | 3.357 | .0001 |
| MEDBLD | 2848 | 0 | 211 | 366 | .441 | .0001 | 2.507 | .0001 |
| OPSBLD | 1008 | 0 | 147 | 191 | .424 | .0001 | 4.622 | .0001 |
| MNTBLD | 2303 | 0 | 563 | 519 | .576 | .0001 | 2.306 | .0001 |
| STOBLD | 7740 | 0 | 1431 | 1690 | -.048 | .3263 | -0.059 | .6526 |
| RDTBLD | 2352 | 0 | 139 | 358 | .225 | .0164 | 1.309 | .0329 |
| UTPBLD | 255 | 0 | 54 | 46 | .588 | .0001 | 26.743 | .0001 |
| ADMBLD | 1964 | 4 | 435 | 391 | .570 | .0001 | 3.035 | .0001 |
| OTHBLD | 620 | 8 | 42 | 110 | .143 | .0893 | 2.698 | .1787 |
| MDEFICIT | 382706 | -1280 | 40956 | 55836 | .586 | .0001 | 0.022 | .0001 |

*Values are for 90 cases.

**Person's r for paired variables consisting of $Q_{ad}$ and the given variable.

***Significance determined by two-tailed t-test.

statistical measures. The first measure, the correlation coefficient, represents the zero-order correlation between the pair of variables and no controls for the influence of other variables are made. It is used to measure the strength of relationship in terms of goodness of fit of a linear regression line to the data. The test of significance of the correlation coefficient is derived from Student's t and the reported value indicates the results of testing the hypothesis that the coefficient is not significantly different from zero. The slope estimate indicates the average change in $Q_{ad}$ associated with a unit change in the respective building category variable.

Among the building category variables, correlation coefficients range from a high value of 0.838 for family housing to an extremely low value of -0.048 for storage buildings. The scattergram depiction of plotted values of this latter variable with average daily water use ($Q_{ad}$), indicated outlier values representing high quantities of average daily water use and low gross floor area for storage buildings creating an upward bias in this region in the regression slope and a weak correlation coefficient. The results of this effect is to force an inverse relationship between the paired variables as noted by the negative signs for both measures. The slope for the variable is very small in comparison to other building variables with a similar range of values, such as bachelor buildings at 0.863. The category of "other" buildings also displayed a plot of paired values with outlier values representing low quantities of water use and high values of gross floor area in this category. The bias is downward and also results in an unreliable regression coefficient.

Rather than remove the outliers at this point in the analysis, they were retained for further examination where they were transformed by grouping with sister categories to form new independent variables. Moreover, the outlier values differed between the storage and other building categories and complete withdrawal would result in the loss of considerable information regarding the relationship of water use with the remaining categories of buildings that these outliers possessed.

The other ten categories of buildings showed data structures with highly significant correlation coefficients as well as regression coefficients. The moisture deficit factor is also shown as equally significant by both measures.

Average daily water use requires a fuller explanation than that offered by the separate single categories of buildings. It has been postulated that it is a function of all of the building areas combined. Multiple regression facilitates the analysis of the combined effects of all independent variables, assuming that they are not perfectly correlated with one another.

## Initial Multiple Regression Analysis

A preliminary multiple regression analysis was performed in which average daily water use was regressed on all 13 independent variables (Table 23). The partial coefficients for family housing, bachelor soldier quarters and research buildings are significant below the criterion level of .05 based on a two-tailed t-test. All other independent variable coefficients are statistically insignificant

TABLE 23

INITIAL MULTIPLE REGRESSION ANALYSIS
(Dependent Variable: Average Daily Water in k-gallons)

| Independent Variable | Partial Coefficient | t-Value | Significance of t |
|---|---|---|---|
| FAMBLD | 0.399 | 2.889 | 0.005 |
| BACBLD | 0.337 | 2.12 | 0.030 |
| TRADBLD | -0.324 | -1.030 | 0.306 |
| COMBLD | 1.023 | 1.453 | 0.150 |
| MEDBLD | 0.188 | 0.477 | 0.635 |
| OPSBLD | 0.158 | 0.220 | 0.827 |
| MNTBLD | 0.243 | 0.682 | 0.497 |
| STOBLD | 0.063 | 0.828 | 0.410 |
| RDTBLD | 1.616 | 4.345 | <0.001 |
| UTPBLD | -2.292 | -0.611 | 0.543 |
| ADMBLD | 0.569 | 1.504 | 0.137 |
| OTHBLD | -1.034 | -0.858 | 0.394 |
| MDEFICIT | -0.002 | -0.800 | 0.462 |
| (Constant Term) | -61.559 | -0.323 | 0.747 |

Coefficient of Multiple Determination ($R^2$ = .809
Standard Error of the Estimate = 976 k-gallons
F-Ratio = 24.822
Degrees of Freedom = 13 and 76
F-Significance = <.0001

indicating that each failed to reject the null hypothesis that their values were not different from zero. Yet the $R^2$ for the equation is substantial at 0.809. Lewis-Beck (1982) reports this type of condition as a rather sure symptom of high multicollinearity.

## Assessment of High Multicollinearity

Although independent variables are virtually always intercorrelated, high multicollinearity is a condition in which one independent variable approaches a perfect linear functional relationship with another independent variable. The consequence, if this condition is present, is that serious parameter estimation problems arise, causing them to be unreliable. There can be little confidence that a particular slope estimate accurately reflects the impact of the independent variable on average daily water use.

Bivariate correlations were computed for each independent variable with all others (Table 24). The matrix shows that the correlation coefficients between family housing, bachelor buildings and community buildings are high at 0.856, 0.875 and 0.891. Coefficients greater than 0.7 exist between training and bachelor buildings (0.730) and training and community buildings (0.763).

Although these high values are suggestive of the presence of high multicollinearity among these variables, particularly those in excess of 0.8, the correlation matrix does not account for the relationship of one independent variable with all the other independent variables. It is possible that one independent variable may be a nearly perfect linear

TABLE 24

BIVARIATE CORRELATION MATRIX BETWEEN PAIRS OF VARIABLES

| | TRABLD | MNTBLD | POTBLD | MEDBLD | ADMBLD | BACBLD | COMBLD | FAMBLD | OPSBLD | UTFBLD | OTHBLD | STOBLD | MDEFICIT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TRABLD | 1.000 | 0.400 | 0.012 | 0.380 | 0.506 | 0.730 | 0.763 | 0.650 | 0.309 | 0.475 | 0.282 | -0.220 | 0.443 |
| MNTBLD | 0.400 | 1.000 | -0.075 | 0.218 | 0.375 | 0.613 | 0.570 | 0.615 | 0.579 | 0.501 | 0.039 | 0.313 | 0.620 |
| BPTBLD | 0.012 | -0.075 | 1.000 | 0.038 | 0.242 | -0.133 | -0.027 | -0.014 | -0.070 | 0.342 | 0.048 | 0.030 | 0.043 |
| MEDBLD | 0.380 | 0.218 | 0.038 | 1.000 | 0.360 | 0.483 | 0.519 | 0.441 | 0.219 | 0.334 | 0.518 | -0.181 | 0.250 |
| ADMBLD | 0.506 | 0.375 | 0.242 | 0.369 | 1.000 | 0.406 | 0.571 | 0.502 | 0.172 | 0.521 | 0.174 | -0.074 | 0.255 |
| BACBLD | 0.730 | 0.613 | -0.133 | 0.483 | 0.406 | 1.000 | 0.875 | 0.865 | 0.486 | 0.496 | 0.192 | -0.163 | 0.668 |
| COMBLD | 0.763 | 0.570 | -0.027 | 0.519 | 0.571 | 0.875 | 1.000 | 0.891 | 0.437 | 0.641 | 0.301 | -0.129 | 0.612 |
| FAMBLD | 0.650 | 0.615 | -0.014 | 0.441 | 0.502 | 0.865 | 0.891 | 1.000 | 0.455 | 0.526 | 0.154 | -0.137 | 0.661 |
| OPSBLD | 0.309 | 0.579 | -0.070 | 0.219 | 0.172 | 0.486 | 0.437 | 0.455 | 1.000 | 0.378 | -0.061 | 0.197 | 0.494 |
| UTFBLD | 0.475 | 0.501 | 0.342 | 0.334 | 0.521 | 0.496 | 0.641 | 0.526 | 0.378 | 1.000 | 0.204 | 0.076 | 0.369 |
| OTHBLD | 0.292 | 0.939 | 0.084 | 0.518 | 0.174 | 0.192 | 0.301 | 0.154 | -0.061 | 0.204 | 1.000 | -0.160 | 0.025 |
| STOBLD | -0.220 | 0.313 | 0.030 | -0.181 | -0.074 | -0.163 | -0.129 | -0.137 | 0.197 | 0.976 | -0.160 | 1.000 | 0.099 |
| MDEFICIT | 0.443 | 0.620 | 0.043 | 0.250 | 0.255 | 0.668 | 0.612 | 0.661 | 0.494 | 0.369 | 0.925 | 0.099 | 1.000 |

combination of the remaining independent variables, even though the bivariate correlation coefficients are not large. The method for assessing this potential hidden condition is to regress each independent variable on all of the other independent variables. If any of the coefficients of multiple determination ($R^2$) from these equations approach 1.0, there is high multicollinearity.

The analysis was performed and the results are displayed in Table 25. The coefficients of multiple determination for community, bachelor and family housing buildings exceed 0.85 and provide evidence that high multicollinearity is detectable. The next section discusses the strategy implemented to correct this problem.

## Strategy for Dealing with High Multicollinearity

An appropriate strategy for correcting the effects of high multicollinearity is to combine those independent variables that are highly intercorrelated into a single indicator. Conceptually, it was proposed that building sectors could be grouped to form new independent variables to represent sectors of water use. Thus, the strategy for coping with high multicollinearity aligns directly with the main idea of the proposed water use model. It remains to be determined, however, which variables should be grouped accordingly. Factor analysis assumes that observed variables are linear combinations of some underlying factor which, in this case, is construed to be identifiable water use sectors. A discussion follows on factor analysis application and the

TABLE 25

REGRESSION ASSESSMENT FOR HIGH MULTICOLLINEARITY

| Variable Name | Symbol | Multiple $R^2$ * |
|---|---|---|
| Family housing | FAMBLD | 0.860 |
| Bachelor housing | BACBLD | 0.868 |
| Training buildings | TRABLD | 0.658 |
| Community buildings | COMBLD | 0.913 |
| Medical buildings | MEDBLD | 0.478 |
| Operations buildings area | OPSBLD | 0.425 |
| Maintenance and production buildings | MNTBLD | 0.682 |
| Storage buildings | STOBLD | 0.362 |
| Research development and test buildings | RDTBLD | 0.388 |
| Utility plants | UTPBLD | 0.631 |
| Administration buildings | ADMBLD | 0.425 |
| Other buildings | OTHBLD | 0.386 |
| Average moisture deficit factor | MDEFICIT | 0.592 |

*Coefficients of multiple determination ($R^2$) obtained by regressing each independent variable on all of the others.

manner in which it was adopted in the development of the water use model.

## Grouping Building Categories: Method of Analysis

The grouping of building variables into logical sectors requires all building categories to be included in the final sector constructs. Concurrently, the new sector variables must also reduce the previously demonstrated high multicollinearity. Because all building categories are in identical units of measure, they can be summed to equate to the total sector building area. Factor analysis can assist in defining the sectors which are responsible for the covariation among the observed variables, but the data may not lend itself to a clear allocation of all categories to common factors and may require adjustments that are sensible and prudent.

The building category data was therefore subjected to principal factoring with iterations and varimax rotation to yield the factor pattern shown in Table 26. The coefficients in the table represent both regression weights and correlation coefficients. The eigenstructure of the correlation matrix is represented by four constructs which jointly explain 77.7 percent of variance in the data.

The first factor is highly correlated with bachelor, family, community, and training building areas which may be taken to represent the community profile of the installation. The second factor shows "other" buildings, a very weak predictor of average daily water use, having the strongest correlation. A military activity variable--storage

TABLE 26

RESULTS OF VARIMAX ROTATED PRINCIPAL FACTOR SOLUTION

| Variable | Factor Pattern I | II | III | IV |
|---|---|---|---|---|
| TRABLD | 0.743 | 0.211 | -0.099 | 0.121 |
| MNTBLD | 0.610 | 0.036 | 0.647 | 0.007 |
| RDTBLD | -0.079 | 0.014 | -0.023 | 0.672 |
| MEDBLD | 0.413 | 0.551 | -0.045 | 0.078 |
| ADMBLD | 0.511 | 0.160 | 0.011 | 0.428 |
| BACBLD | 0.936 | 0.160 | 0.054 | -0.117 |
| COMBLD | 0.921 | 0.260 | 0.044 | 0.115 |
| FAMBLD | 0.900 | 0.104 | 0.068 | 0.051 |
| OPSBLD | 0.484 | -0.030 | 0.445 | -0.048 |
| UTPBLD | 0.541 | 0.171 | 0.267 | 0.551 |
| OTHBLD | 0.080 | 0.850 | -0.089 | 0.058 |
| STOBLD | -0.178 | -0.115 | 0.647 | 0.050 |
| Eigenvalue | 5.296 | 1.690 | 1.354 | 0.978 |
| Cumulative % of variance | 44.1 | 58.2 | 69.5 | 77.7 |

buildings--displays the strongest correlation with the third factor. The fourth factor is best represented by RD&T buildings. Water usage represented by this variable is characterized by research and test processes which may require large quantities of water.

Four potential water use sectors were identified which consisted of either single building category variables (other, storage and research) or multiple building categories, which were combined by adding gross floor areas to form a new composite variable. Five building category variables--maintenance, operation, medical, administration, and utility plants--could not be assigned to these four sectors based on the factor analyses. Additional statistical analysis and criteria were established to determine the most appropriate sector to which each of these five variables should be allocated.

The first step was to regress average daily water use on the four variables representing the four water use sectors. The moisture deficit variable was also included as an independent variable. The results of the regression are shown in the following equation. The t-statistic is shown in parenthesis for each corresponding coefficient:

$$
\begin{aligned}
Q_{ao} = \underset{(0.132)}{23.637} + \underset{(12.076)}{.406}\ \text{SECTOR 1} - \underset{(-0.876)}{0.877}\ \text{SECTOR 2} \\
+ \underset{(1.700)}{0.113}\ \text{SECTOR 3} + \underset{(5.490)}{1.641}\ \text{SECTOR 4} - \underset{(-0.672)}{.002}\ \text{MDEFICIT}
\end{aligned}
\tag{6}
$$

$R^2 = 0.783$ $\qquad$ $F = 60.656$

SEE = 997.2 $\qquad$ D.F. = 5 and 84

Where:

SECTOR 1 = Composite variable of the summed total gross floor area of family, bachelor, training and community buildings

SECTOR 2 = Other building gross floor area

SECTOR 3 = Supply building gross floor area

SECTOR 4 = Research building gross floor area.

Each of the remaining five building categories were subjected separately to a series of regression analyses in which their corresponding floor areas were added one at a time to each sector. For example, the gross floor area of the maintenance category was added to SECTOR 1, then SECTOR 2 through SECTOR 4 with a regression analysis performed for each successive assignment. The change in $R^2$ was observed at each step and the building category was finally assigned to the sector which produced the highest multiple $R^2$ value during the regression analyses. At no time during this entire procedure did the $R^2$ value change more than 0.02. Additionally, no building category was assigned to SECTOR 2 based on the $R^2$ criteria and the t-value for its coefficient remained insignificant in every regression procedure. This outcome was expected because "other" buildings, representing this sector, does not contribute meaningfully to explaining the variance of average daily water use.

It was decided, therefore, to analyze the $R^2$ change in the model when this variable was added to the gross floor area of each of the three remaining sectors. The result of the series of regressions was to assign "other" buildings to SECTOR 1.

As a result of these analyses, all building categories were assigned and represented by three distinct water use sectors and are summarized in Table 27. Three identifiable sectors emerge as distinct independent variables: a community service and support sector (COMMON), a military activities sector (MILACT), and a research and post utility support sector (RDTUTIL). The numerical values for the building areas in each factor were summed to form three new variables with labels as shown in the table. The next section describes the data characteristics of these variables and retests for high multicollinearity. These new variables are appropriately referred to as water use sectors in the discussion that follows.

## Characteristics of the Sector Variables

When research buildings were combined with utility plants, the bivariate regression slope of 1.581 is significant below the 0.01 level (Table 28). The effect of grouping maintenance, storage and operations buildings is to reduce the influence of outliers previously noted in the scattergram analysis of storage buildings with average day water use. The sign of the bivariate regression slope for this sector is positive as expected, although significant at the 0.16 level. Outlier influence still exists, but removal is not warranted until the full model is tested using multivariate regression analysis and residuals are examined. The community sector variable is strongly correlated with average daily water use and accounts for .84 of the variance of the dependent variable alone. Regression techniques were again used to

TABLE 27

INDEX OF GROUPED BUILDING CATEGORY VARIABLES

| Factor No. | Grouped Building Categories | | New Independent Variables | Description |
|---|---|---|---|---|
| 1 | FAMBLD<br>BACBLD<br>TRABLD<br>COMBLD<br>MEDBLD<br>ADMBLD<br>OTHBLD | to form | COMMUN | Community service and support sector |
| 2 | OPSBLD<br>MNTBLD<br>STOBLD | to form | MILACT | Military activities sector |
| 3 | RDTBLD<br>UTPBLD | to form | RDTUTIL | Research and post utility support sector |

TABLE 28

SECTOR VARIABLE CHARACTERISTICS*

| Variable Code | High Value | Low Value | Mean | Standard Deviation | Correlation Coefficient** | Correlation Significance | Bivariate Regression Slope | Slope Significance*** |
|---|---|---|---|---|---|---|---|---|
| COMMUN | 19095 | 80 | 4406 | 5089 | .843 | .0001 | .344 | .0001 |
| MILACT | 8787 | 51 | 2141 | 1988 | .150 | .0789 | .157 | .1578 |
| RDTUTIL | 2607 | 0 | 194 | 376 | .286 | .0031 | 1.581 | .0063 |

* Values are for 90 cases.

** Pearson's r for paired variables consisting of $Q_{ad}$ and the given sector variable.

*** Significance determined by two-tailed t-test.

check for the reduction of high multicollinearity observed previously when the individual building categories were assessed separately. The $R^2$ values for each sector and the moisture deficit factor are: COMMUN (0.452); MILACT (0.118); RDTUTIL (0.008); and MDEFICIT (.500). The problem of high multicollinearity is no longer present and the variables are acceptable for evaluation in the water use model.

## Final Model Specification

Having determined three sectors of water use activities, these newly-formed independent variables can be entered into the following linear additive model:

$$Q_{ad} = a + b_1\ (\text{COMMUN}) + b_2\ (\text{MILACT}) + b_3\ (\text{RDTUTIL}) + b_4\ (\text{MDEFICIT}) + e$$

where:

$Q_{ad}$ = average daily installation water use in k-gals

$b_1 \ldots b_4$ = coefficients of the corresponding independent sector variables

COMMUN = community service and support sector in k-sq ft.

MILACT = military activity sector in k-sq ft.

RDTUTIL = research and post utility support sector in k-sq ft.

MDEFICIT = moisture deficit factor (as defined in the conceptualized model).

a = constant term

e = error term

The expected signs of the variables are all positive.

## Results of Model Testing

This water use function was estimated from data on all 90 installations and the full model result was:

$$Q_{ad} = \underset{(-0.90)}{-1.65.05} + \underset{(12.29)}{0.34}\ \mathrm{COMMUN} + \underset{(1.85)}{0.10}\ \mathrm{MILACT} + \underset{(4.99)}{1.40}\ \mathrm{RDTUTIL} - \underset{(-0.21)}{0.005}\ \mathrm{MDEFICIT} \qquad (7)$$

The t-statistic is given in parentheses below each estimated parameter. For 90 installations, the two-tailed critical value at the 95 percent level is 1.98, leaving in doubt the significance of the moisture deficit factor which also exhibits the opposite expected sign. The constant value is also negative in sign and significant at the 0.369 level. The variance explained by the regression equation is measured by the $R^2$ statistic and was 0.784. The F-statistic was 77.10 with 4 and 85 degrees of freedom and significant at the .0001 level. The standard error of estimate or average error in predicting average day water use from the regression equation was 989 k-gallons. An analysis of the residuals scatterplot showed no apparent trend or pattern that would violate the assumptions of regression analysis; however, an extreme outlier was observed, having a standardized residual value of 6.10, contrasted to the next worst outlier having a value of 3.78. This point represented Redstone Arsenal and its presence may have biased the estimates of the parameter coefficients. To determine the influence of

this outlier, the case was removed from the data set and the model again was subjected to regression analysis. The results were:

$$Q_{ad} = \underset{(-0.50)}{63.71} + \underset{(16.90)}{0.33}\ \text{COMMUN} + \underset{(1.76)}{0.07}\ \text{MILACT} + \underset{(3.56)}{0.74}\ \text{RDTUTIL} + \underset{(0.68)}{0.0001}\ \text{MDEFICIT} \qquad (8)$$

The response to the removal of the single outlier is clearly seen in the reduction of the parameter coefficient for the research and post utility support sector variable. This outlier had caused an upward bias in this coefficient. The effect on the other coefficients was slight except for the moisture deficit factor which now reflects the expected positive sign. The multiple $R^2$ value is now increased by nearly 12 percent to 0.874. The standard error of the estimate was reduced to 693 k-gallons, which suggests that prediction error is over 1.5 times as great in the outlier equation. Additionally, the F-value was enhanced to 145.79 with 4 and 84 degrees of freedom and remained highly significant below the .0001 level.

Additional extreme outlier removal did not result in a significant change in the coefficient of multiple determination and the parameter coefficients remained stable. All other cases therefore, were retained for computation of the best fit model. The moisture deficit factor, significant at the 0.496 level, does not contribute to the explanation of average daily water use, but may offer an improved predictive capability if summer seasonal water use data were available for analysis as the dependent variable.

Stepwise regression with forward selection of predictor variables

was used to calibrate the model. Regressions that used the logarithms of the variables also were tested but these equations did not provide higher coefficients of multiple determination. Fitting the combined 89 installations yielded an equation of best fit as follows:

$$Q_{ad} = \underset{(23.53)}{0.339\ \text{COMMUN}} + \underset{(2.13)}{0.079\ \text{MILACT}} + \underset{(3.66)}{0.754\ \text{RDTBLD}} \qquad (6)$$

The t-values are shown in parentheses and all were found to be significant at the 0.05 level. The constant term has been deleted from the equation because it was not significantly different from zero. The value of the constant term was -73.16 with a corresponding t-value of -0.575. The $R^2$ is 0.873 with an F-value of 195.45, significant below the .0001 level. The standard error of the estimate measures 690 k-gallons.

Community service and support sector is by far the most important predictor variable and alone accounts for .846 of the variance of the dependent variable in the best fit equation (Table 29). The military activity sector and the research and post utility support variable are statistically significant but their effect is very small compared to the community service and support sector. They do provide a genuine explanation of a portion of the variance of water use; however, their relative importance should be recognized and understood.

The interpretation of the parameter estimates of the best fit equation is straightforward. For example, a one-unit (1000 square feet) increase in the building floor area of the community service sector would result in a 339 gallon per day increase in average water service.

**TABLE 29**

**REGRESSION EQUATIONS: SUMMARY OF EMPIRICAL RESULTS**

| Regression Equation (Standardized coefficients and t-statistics given in parentheses above and below, respectively). | Selected Statistics $R^2$ | SEE | F | N |
|---|---|---|---|---|
| **Theoretical Equation:** | | | | |
| $Q_{ad} = a + b_1\ (\mathrm{COMMUN}) + b_2\ (\mathrm{MILACT}) + b_3\ (\mathrm{RDTUTIL}) + b_4\ (\mathrm{MDEFICIT}) + e$ | | | | |
| **Intermediate Equations:** | | | | |
| $Q_{ad} = \underset{(-.90)}{-165.05} + \overset{(.837)}{\underset{(12.29)}{0.34}}\ \mathrm{COMMUN} + \overset{(.099)}{\underset{(1.85)}{0.10}}\ \mathrm{MILACT} + \overset{(.252)}{\underset{(4.99)}{1.40}}\ \mathrm{RDTUTIL} - \overset{(-.014)}{\underset{(-0.21)}{0.0005}}\ \mathrm{MDEFICIT}$ | .784 | 989 | 77.1 | 90 |
| $Q_{ad} = \underset{(-.50)}{-63.71} + \overset{(.886)}{\underset{(16.90)}{0.33}}\ \mathrm{COMMUN} + \overset{(0.73)}{\underset{(1.76)}{0.07}}\ \mathrm{MILACT} + \overset{(.139)}{\underset{(3.56)}{0.74}}\ \mathrm{RDTUTIL} + \overset{(.038)}{\underset{(0.68)}{0.0001}}\ \mathrm{MDEFICIT}$ | .874 | 693 | 145.8 | 89 |
| **Best Fit Equation:** | | | | |
| $Q_{ad} = \overset{(.910)}{\underset{(23.53)}{0.339}}\ \mathrm{COMMUN} + \overset{(.082)}{\underset{(2.13)}{0.079}}\ \mathrm{MILACT} + \overset{(.141)}{\underset{(3.66)}{0.754}}\ \mathrm{RDTUTIL}$ | .873 | 690 | 195.4 | 89 |

It is reasonable to expect that a family housing unit of 1500 square feet would cause an increase of 496.5 gallons. This increase would suggest a 165.5 gallons per capita per day for a family of three persons. Similarly, a one-unit increase in the gross square footage of buildings in the research and post utility support sector would correspondingly increase average daily water service by 754 gallons. The coefficient for the military activity sector can be interpreted in the same manner: average water use will increase by 79 gallons per day for a one-unit increase in the buildings within this sector.

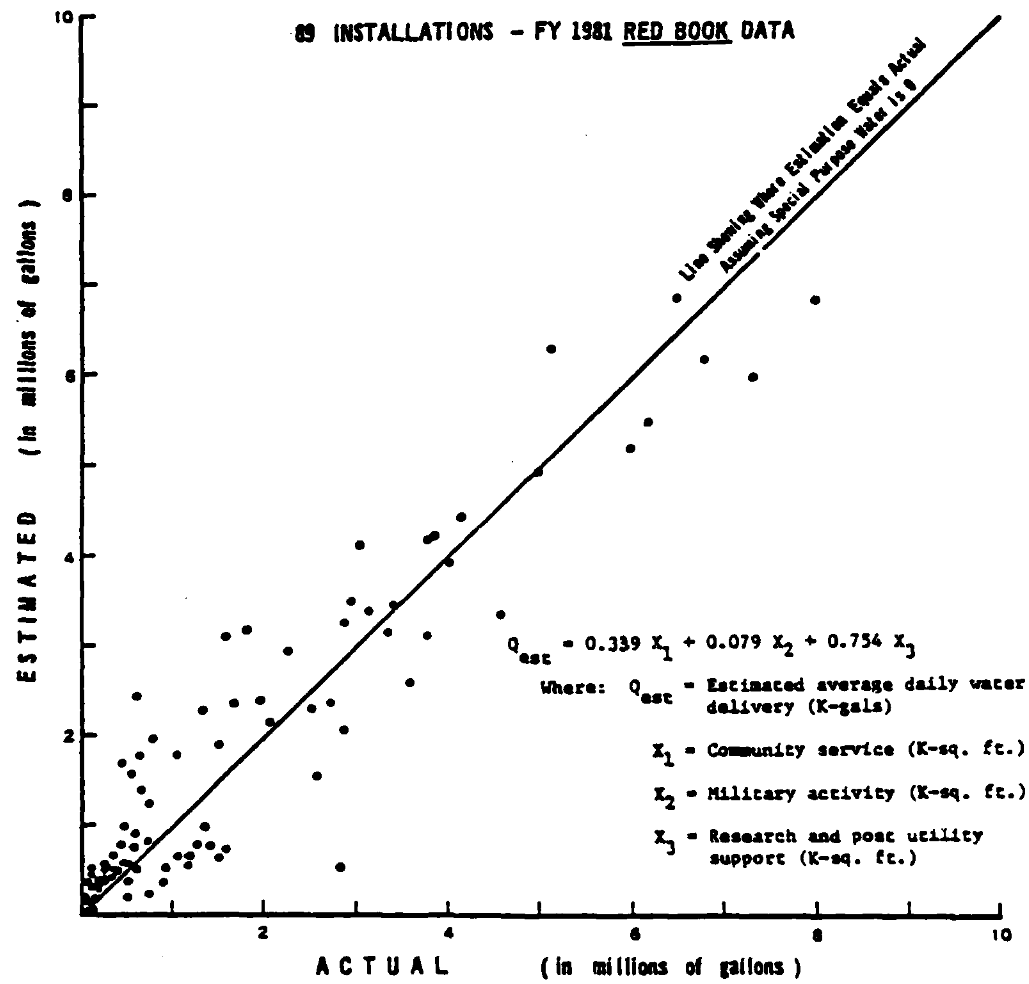
The sector coefficients may also be used to provide a rough measure of disaggregated water use for the purpose of evaluating potential water conservation measures. For example, water use in bachelor housing may be approximated by the product of the total building area in this category on a given installation and the coefficient value of 0.339 for the community service sector. The resultant quantity of water could be used as the representative average daily use in obtaining estimates of the effectiveness of a conservation measure under consideration. The expected fractional reduction in use and the expected coverage attributed to implementing the measure would also be required to complete an effectiveness evaluation.

The standard error of estimate in the equation represents the unexplained variance of the dependent variable. The proportion of cases that fall between $\pm$ 1 standard error of the estimate was determined to be 77.8 percent (69 of 89 cases). Reduction in standard error may be possible if the value of average daily water use were adjusted to account for leaks in the distribution system. This would tend to

improve underestimated values of installations where water losses of this type occur. Water sold to off-post customers, if any, may also improve low-sided estimates if such sale quantities were deleted from the value of the dependent variable. In general, average daily water use is a weak measure of water service and requires further disaggregation into monthly or seasonal values to be able to reassess the moisture deficit factor and potentially reduce error by further explanation.

## Comparing Procedures: Current Guidelines Versus Requirement Model

A plot of the actual versus estimated values of average daily water use is shown in Figure 4. It can be contrasted with Figure 3 (Chapter IV) which duplicates the values obtained by applying current Army procedural guidelines for estimating the same dependent variable. It is clear that better estimation and prediction procedure is offered by the requirement model presented in this study. The linear additive model developed in this chapter has improved the power of prediction substantially. Current Army procedures yield an $R^2$ value of 0.564 compared to 0.873 for the model. The standard error of the estimate has been reduced by 50 percent from 1374 to 690 k-gallons per day. Estimated values for each installation using both procedures is given in Appendix D. Although the model provides substantial improvement, it is limited to predicting average daily water use only and requires additional evaluation with data representing summer and winter water use.




COMPARISON OF ACTUAL VS. ESTIMATED AVERAGE DAILY
WATER SERVICE APPLYING REVISED LINEAR ADDITIVE
MODEL WITHOUT OUTLIER
(Redstone Arsenal)

Figure 4

## Summary

The results of the analysis and investigative procedures lend support to the general conclusion that it is possible to identify independent sectors of water use by grouping specific building categories.

The analysis, although limited in scope, showed the existence of three statistically significant sectors of water use: a community service and support sector, a military activity sector and a research and post utility support sector. When empirical data representing these sectors were tested within a conceptualized linear additive model, the result was to explain 87 percent of the variance of average daily water use. A moisture deficit factor failed to meet statistical criteria for inclusion in the best fit model; however, it was shown to be positively related to average daily use.

The model would be of great utility to installation planners, not only to forecast water use in a peacetime setting, but also as an aid in estimating sectoral water use for water conservation effectiveness evaluation. Further refinement of the measure and time period of water use is required to test the reaction of the model framework and potentially improve the accuracy of the estimate.

The empirical data required to use the model is readily available to all installation facility engineers. With knowledge of expected future construction or destruction of buildings, the impact on average day water service can be forecasted and evaluated in accordance with the model specifications.

# CHAPTER VI

# CONCLUSIONS AND RECOMMENDATIONS

## Summary of Findings

The purpose of this study was to gather information that would characterize the state of water planning on Army installations and explore the possibility of developing an improved analytical tool for estimating and forecasting installation water requirements. The study addressed two major questions. These were:

1. What is the nature and types of water planning being practiced by installation water utility managers?

2. How can procedures for estimating installation water requirements be improved to provide a basis for other essential water planning activities?

The first question was concerned with gathering information from existing data bases or acquiring new data to provide a broadened perspective on what planners are doing to prepare for water supply problems expected to occur by the turn of this century. Specifically, a recent study conducted by the National Defense Institute concluded that nine out of ten Army installations were located in hydrologic areas where impending water shortages or water quality problems would occur in the near future. The impact would be exposed in rising maintenance

and operation costs associated with installation water service and the report strongly recommended that each branch of military service formulate a strategy to curb costs through improved water demand management programs. To do so requires knowledge regarding on-going water planning efforts at the installation level in order to identify planning shortfalls and develop the planning guidelines to fill the gaps.

This study provides an assessment of the current status of water planning at the installation level. An analysis of average costs for water utility operation, maintenance and repair indicates that combined average costs are increasing significantly in real dollars, pointing to mounting pressures for larger budget allocations for these activities. These costs are likely to continue to rise, particularly on posts where aging system components will need replacement. Capacity requirements will have to be reevaluated in light of demand reduction opportunities offered by water conservation programs. Within the study area, FORSCOM and TRADOC installations reflect typically below average operating costs. DARCOM and the remaining grouped Major Commands generally have exhibited higher than average costs for water service operation, attributed in part to their characteristic single source of water supply.

Improved water planning procedures would provide a platform for developing ways to curb these costs. The <u>current</u> emphasis on water planning and the procedural guidelines available to planners are inadequate in three areas: forecasting, water shortage contingency planning, and procedural assessment of potential water conservation

measures. The justification for this conclusion is embedded in the findings of this study.

The results of a mail survey, in which 86 installations responded, indicated that more than one-third did not know what quantities of water would be needed to support Fiscal Year 1990 requirements. Even among those posts which adjudged a general direction in future water needs (increase, decrease, or remain about the same in FY 1983 levels), only about one-fourth of the reporting stations have apparently evaluated water needs for the future using a planning method that goes beyond judgmental planning. The 22 water use forecasts that have been done, however, are based on a per capita or adjusted per capita approach, which does not facilitate the evaluation of water conservation measures.

Indicators of water planning were assessed and included the status of water shortage contingency plans and water conservation programs. Documented contingency plans are more likely to be found on FORSCOM and TRADOC installations, while no plans predominate among DARCOM stations, where single sources of water supply prevail. The majority of installations (59%) indicated that plans were not on-hand and reflects a need to increase planning emphasis in this area.

There is no water conservation policy disseminated throughout Army installations and as a result, 55 (64%) of the surveyed installations indicate that they have not implemented a water conservation program within the past five year. Moreover, the types of conservation measures being executed are limited primarily to irrigation restrictions and reduced flow plumbing fixtures, and in most instances, the benefit or costs of having implemented these measures have not been quantified. It

would appear that a mandated water conservation policy would provide a stimulus to broaden this water planning effort; however, procedural guidelines are needed to assist installation planners in evaluating potentially adaptable and socially acceptable conservation actions.

The second research question was concerned with the formulation of an improved planning method to estimate installation peacetime water requirements. An evaluation of current Army procedures for estimating average daily water demand was conducted and major discrepancies were found. The measure of effective population, a key parameter in these procedures, is suspicious due to the questionable weights applied to resident and non-resident groupings. The data representing effective population in the Redbook cannot be used to determine per capita average daily water use because of errors in the method by which it is computed. The current procedures for estimating average daily water use were demonstrated, using the Redbook effective population data for FY 81, then compared to actual water use values for the same 90 installations in the study area. The results show that the current method of estimation is unreliable and attempts to predict future use using this procedure would be unacceptable.

A major dilemma associated with both water requirement estimation and water conservation planning for Army installations has been the inability to disaggregate water use into reasonable sectors. Metered data or billing information would normally provide the base source for assessing sector water use patterns; however, water is not priced and rarely metered on Army installations. Independent sectors of water use

can be identified and the results of the analysis and investigative procedures discussed in Chapter V found that there exists three statistically significant sectors of water use composed of groups of specific building categories: a community service and support sector, a military activity sector and a research and post utility support sector.

When empirical data representing these sectors were tested within a conceptualized linear additive model, the result was to explain 87 percent of the variance of average daily water use. A moisture deficit factor failed to meet statistical criteria for inclusion in the best fit model; however, it was shown to be positively related to average daily use.

The model would be of great utility to installation planners, not only to predict water use in a peacetime setting, but also as an aid in estimating sectoral water use for water conservation effectiveness evaluation. Further refinement of the measure and time period of water use is required to test the reaction of the model framework and potentially improve the accuracy of the estimate.

The empirical data required to use the model is readily available to all installation facility engineers. With knowledge of expected future construction or destruction of buildings, the impact on average day water service can be estimated.

## Recommendations

The results of this study provide a valuable foundation for improving water planning on Army installations in the contiguous United States. Installation managers should be apprised of the trend in rising average costs and the current state of water planning described in this report to announce that there are inadequacies that need corrective action and planning attention. Publication and distribution of the findings of this study to installation facility engineers can stimulate the needed interest in water resource planning and a resolve to sharpen planning procedures.

The Department of the Army should consider taking action to amend current guidelines for estimating average daily water use. The procedures may not be acceptable and application could mislead decision-makers confronted with allocating defense dollars for installation water utilities. The measure of effective population should not be used to approximate average per capita water use.

It is further recommended that these existing guidelines be replaced with the water requirement model developed and tested in this study. It not only outperforms existing procedures, but also facilitates the evaluation of potential conservation measures for specific water use sectors. Ideally, the technique can be operationalized as a module into the computerized Integrated Facilities System available to facility engineering directorates. A user-friendly manual would make application straightforward and result in timely estimates and forecasting of water requirements. To reach this goal, a

study should be undertaken to develop procedures for projecting the values of the parameters of the model and to explore the possibility of developing seasonal models using monthly water use data. It is further urged that the research team include experts in water requirement forecasting and computer application comparable to the IWR MAIN method recently developed by the Corps' Institute for Water Resources. With these procedures in hand, facility engineers can conduct further analyses of conservation measures, water shortage contingency plan development and improved estimates of installation expansion capabilities.

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# APPENDIX A

# THE MAIL SURVEY INSTRUMENT AND LETTERS

DEPARTMENT OF THE ARMY
UNITED STATES ARMY STUDENT DETACHMENT
FORT BENJAMIN HARRISON, INDIANA 46216

26 December 1983

(PRE-TEST COVER LETTER)

In our recent telephone conversation, I explained to you the scope of my dissertation research which intends to examine the nature and character of water supply, water use and water conservation on US Army installations within the 48 contiguous states. I am most grateful to be given the opportunity to visit and discuss these topics with your water utility manager and I have enclosed a verification card regarding this January appointment.

In advance of my arrival, may I request that your utility manager, whom I will meet with during my upcoming visit, complete the inclosed questionnaire which we can use as the basis for our discussions. Please do not mail the questionnaire or other requested materials to me. I will gather these materials during my visit and they will be integrated into the composite analysis of Army-wide community water supplies.

If you have any questions, I can be contacted through my office at Southern Illinois University, telephone (618) 536-3375. Thank you for your cooperation and I look forward to our forthcoming meeting.

Sincerely,

JOHN F. LANGOWSKI, JR.
Lieutenant Colonel, Corps of Engineers
United States Army

2 Inclosures
As stated

**DEPARTMENT OF THE ARMY**
**UNITED STATES ARMY STUDENT DETACHMENT**
**FORT BENJAMIN HARRISON, INDIANA 46216**

11 January 1984

(INITIAL MAILING COVER LETTER)

Dear Sir:

I am currently assigned for duty at Southern Illinois University for the purpose of completing my doctoral dissertation. I have designed my research to investigate the nature and character of water supply, water use and water conservation on U.S. Army fixed installations within the 48 contiguous states. Your installation, along with others, has been selected to assist in determining the existing role of water use forecasting and water conservation in DEH/FE planning, as well as the need for improved guidance and procedures.

I would greatly appreciate your assistance in completing the attached questionnaire at the inclosure to this letter. Your response bears directly on the composite results of this Army-wide study of military community water supplies. Your participation in this study has been cleared with your MACOM Engineer and with the Deputy Director for Facilities Engineering and Housing, Office of the Chief of Engineers. When the final analysis is completed, a summmary report will be furnished for your review.

May I request that the respondent chosen to answer the questionnaire be knowledgeable and experienced in the planning,operation and maintenance of water supply activities on your installation and occupy a principal management position in this area.

I shall be very appreciative if you would complete the enclosed questionnaire and mail it to me in the self-addressed, stamped envelope by 25 January 1984. If you have any questions, I can be contacted at (618) 536-3375. Thank you for your cooperation.

Sincerely,

JOHN F. LANGOWSKI, JR.
Lieutenant Colonel, Corps of Engineers
United States Army

Inclosure
As stated

**DEPARTMENT OF THE ARMY**
UNITED STATES ARMY STUDENT DETACHMENT
FORT BENJAMIN HARRISON, INDIANA 46216

6 February 1984

(FIRST REMINDER LETTER)

Dear Sir:

In my previous letter dated 11 January 1984, I requested your assistance in completing a questionnaire pertaining to the nature of water supply, water use and water conservation at your installation. To date, the response rate from CONUS installations has been very helpful and will enhance the effectiveness of this important study; however, my records indicate that I have not heard from you. I would still be very grateful if I could obtain the information relative to the operations and maintenance of water services and systems on your post.

If you overlooked sending the questionnaire or feel you did not have ample time to complete the questionnaire by 25 January, I would still appreciate your response. If, on the other hand, you did not receive the questionnaire or have questions about it, please call me at Southern Illinois University, (618) 536-3375. I look forward to hearing from you.

Sincerely,

JOHN F. LANGOWSKI, JR.
Lieutenant Colonel, Corps of Engineers
United States Army

**DEPARTMENT OF THE ARMY**
**UNITED STATES ARMY STUDENT DETACHMENT**
**FORT BENJAMIN HARRISON, INDIANA 46216**

12 March 1984

(SECOND REMINDER LETTER)

Dear Sir:

In my previous letters dated 11 January 1984 and 6 February 1984, I requested your assistance in completing a questionnaire pertaining to the nature of water supply, water use and water conservation at your installation. To date, the response rate from CONUS installations has been very helpful and will enhance the effectiveness of this important study; however, my records indicate that I have not heard from you. I would still be very grateful if I could obtain the information relative to the operation and maintenance of water services and systems on your post.

I am again enclosing the questionnaire and a self-addressed return envelope for your convenience. Your response bears directly on the composite results of this Army-wide study of military community water supplies. Your participation in this study has been cleared with your MACOM Engineer and with the Deputy Director for Facilities Engineering and Housing, Office of the Chief of Engineers. When the final analysis is completed, a summary report will be furnished for your review.

May I request that the respondent chosen to answer the questionnaire be knowledgeable and experienced in the planning, operation and maintenance of water supply activities on your installation and occupy a principal management position in this area.

If you overlooked sending the questionnaire or feel you did not have ample time to complete the questionnaire, I would still appreciate your response. Your mailed reply by 30 March 1984 would ensure timely inclusion in the analysis. If, on the other hand, you have questions about it, please call me at Southern Illinois University, (618) 536-3375. I look forward to hearing from you.

Sincerely,

JOHN F. LANGOWSKI, JR.
Lieutenant Colonel, Corps of Engineers
United States Army

Inclosure
As stated

**WATER SUPPLY AND USAGE ON US ARMY FIXED INSTALLATIONS**

The following questions refer to various characteristics of the water supplied and used on US Army installations located within the contiguous United States. Your thoughtful consideration in responding to this information request will contribute in determining an Army-wide characterization and analysis of DEH/FE planning and operations of military community water supplies. Your response, along with others, will assist in this study to find out the role of water use forecasting and water conservation in DEH/FE planning, as well as the need, if any, for improved guidance and procedures.

I shall be very appreciative if you would complete the attached questionnaire and mail it to me in the self-addressed, stamped envelope by 25 January 1984. Thank you for your cooperation.

IF YOU HAVE ANY QUESTIONS, PLEASE CALL LTC JOHN LANGOWSKI

AT (618) 536-3375 BETWEEN 0900 - 1600 HOURS, CST

1. Please complete the following table to show the fiscal year total effective population for your installation and the total fiscal year quantity of water in 1000 gallon (k-gallon) units required from each of the listed sources of water supply.

| | Total Effective Population | Total Purchased Water | Total Self-Supplied from Surface Sources | Total Self-Supplied from Wells |
|---|---|---|---|---|
| FY 1982 | ____ persons | ____ k-gallons | ____ k-gallons | ____ k-gallons |
| FY 1983 | ____ persons | ____ k-gallons | ____ k-gallons | ____ k-gallons |
| Projected for FY 1990 (please check) | ____ increase<br>____ decrease<br>____ remain about the same as FY 1983<br>____ don't know | ____ increase<br>____ decrease<br>____ remain about the same as FY 1983<br>____ don't know | ____ increase<br>____ decrease<br>____ remain about the same as FY 1983<br>____ don't know | ____ increase<br>____ decrease<br>____ remain about the same as FY 1983<br>____ don't know |

2. Communities or other activities outside of your installation may be receiving some amount of water supply from post facilities:

a. Does your installation provide water to off-post customers? (Please check)

_______ No. Water is not being furnished to off-post customers through installation facilities. (If you checked this answer, go to Question 3.)

_______ Yes, but only in the event of an emergency requirement and the type of water being supplied is (please check):

_______ raw water _______ treated water _______ both

_______ Yes, on a regular interval basis and the type of water being supplied is (please check):

_______ raw water _______ treated water _______ both

b. Indicate the total annual quantity of water (in k-gallons) supplied to off-post customers:

| | |
|---|---|
| FY 1982 | _______ k-gallons or _______ data not available |
| FY 1983 | _______ k-gallons or _______ data not available |
| Projected for FY 1990 | _______ k-gallons or _______ data not available |

c. Indicate how often and for what reasons water is supplied or is to be supplied to off-post customers:

| | Number of Days per Fiscal Year | Reasons(s) for Providing Off-post Water Service |
|---|---|---|
| FY 1982 | | |
| FY 1983 | | |
| Projected for FY 1990 | | |

3. Please check the applicable box(s) that indicate the type of meter currently in place for each of the following water user categories: (If none, then write NONE)

| Category of Water User | Individual Connection Meter (please check) | Sub-area Master Meter (please check) | Installation Master (Meter) (please check) |
|---|---|---|---|
| Temporary/Transient Quarters | | | |
| Family Housing | | | |
| Bachelor Soldier Quarters | | | |
| Main/Branch Post Exchange | | | |
| Commissary | | | |
| Bank | | | |
| Post Office | | | |
| Credit Union | | | |
| AAFES Gas Station(s) | | | |
| AAFES Laundromats | | | |
| AAFES Cafeterias/Restaurants | | | |
| Main Clubs/Annexes | | | |
| Soldier Dining Facilities | | | |
| Gymnasiums | | | |
| Swimming Pools | | | |
| Other Indoor Recreational Activities (please specify) | | | |
| | | | |
| | | | |
| Hospitals | | | |
| Medical Clinics | | | |
| Dependent Schools | | | |
| Military Vehicle Wash Facilities | | | |
| Military Laundry/Dry Cleaning | | | |
| Military Vehicle Maintenance | | | |
| R & D Laboratories | | | |
| Boilers and Steam Generation | | | |
| Metal Cleaning & Plating | | | |
| Cooling Towers & Wet Scrubbers | | | |
| Administration Offices | | | |
| Command-level Headquarters | | | |
| Soldier Instructional Facilities | | | |
| Communications Facilities | | | |
| Landscape Irrigation | | | |
| Air Terminal Operations | | | |
| Emergency Fire Water | | | |
| Off-post Customers | | | |
| Other Categories not listed above (Please specify) | | | |

4. a. Do any of the above categories of water users listed in Question 3 pay directly in dollar charges (not as a housing allowance) for their water service? (Please check)

Yes ________ No ________ (If you checked No, go on to Question 5.)

b. If you checked yes, please list the specific water user categories and the billing period interval.

| Customer Category | Billing Frequency |
|---|---|
| ________ | ________ |
| ________ | ________ |
| ________ | ________ |
| ________ | ________ |
| ________ | ________ |
| ________ | ________ |
| ________ | ________ |
| ________ | ________ |
| ________ | ________ |
| ________ | ________ |

5. Has there been a study done within the past 5 years that has included a forecast of future water needs for your installation?

________ Yes. (Please include a copy of this study and any others which analyze water use forecasts or patterns on your installation. Send them along with this completed questionnaire.)

________ No. (If you checked this answer, go on to Question 12.)

| QUESTIONS | ANSWERS | | |
|---|---|---|---|
| | Study No. 1 | Study No. 2 | Study No. 3 |
| 6. What recent studies (last 5 years) of your installation included water use forecasts? (Please name only one study for each box) | | | |
| 7. For each study, who performed the water use forecasts? (Please check) | Corps District Personnel ____<br>Consultant to Corps District ____<br>DEH/FE In-house Personnel ____<br>Consultant to DEH/FE ____ | Corps District Personnel ____<br>Consultant to Corps District ____<br>DEH/FE In-house Personnel ____<br>Consultant to DEH/FE ____ | Corps District Personnel ____<br>Consultant to Corps District ____<br>DEH/FE In-house Personnel ____<br>Consultant to DEH/FE ____ |
| 8. For each study, what was the forecast period? Please identify the <u>base</u> year and the <u>last</u> year or other time increment. | Base year ____<br>Last year ____<br>Other time increment:<br>Base unit ____<br>Last unit ____ | Base year ____<br>Last year ____<br>Other time increment:<br>Base unit ____<br>Last unit ____ | Base year ____<br>Last year ____<br>Other time increment:<br>Base unit ____<br>Last unit ____ |
| 9. What was the forecast unit or units? (Please check) | Annual water use ____<br>Average day water use ____<br>Maximum day water use ____<br>Seasonal water use ____<br>Maximum month water use ____<br>Other: ____<br>(Briefly describe on separate sheet) | Annual water use ____<br>Average day water use ____<br>Maximum day water use ____<br>Seasonal water use ____<br>Maximum month water use ____<br>Other: ____<br>(Briefly describe on separate sheet) | Annual water use ____<br>Average day water use ____<br>Maximum day water use ____<br>Seasonal water use ____<br>Maximum month water use ____<br>Other: ____<br>(Briefly describe on separate sheet) |
| 10. What types of water use were forecasted? | Total water use ____<br>Family Housing water use ____<br>Commercial water use ____<br>Industrial water use ____<br>Irrigation water use ____<br>Leaks & unaccounted water use ____<br>Mobilization water use ____ | Total water use ____<br>Family Housing water use ____<br>Commercial water use ____<br>Industrial water use ____<br>Irrigation water use ____<br>Leaks & unaccounted water use ____<br>Mobilization water use ____ | Total water use ____<br>Family Housing water use ____<br>Commercial water use ____<br>Industrial water use ____<br>Irrigation water use ____<br>Leaks & unaccounted water use ____<br>Mobilization wator use ____ |
| 11. What method(s) were used to make the forecast? | Population times per capita use ____<br>Effective population adjusted by a capacity factor, then times per capita use ____<br>Statistical Analytical Method ____<br>Judgment method based on opinions of DEH/FE personnel ____<br>Other ____<br>(Briefly describe on separate sheet) | Population times per capita use ____<br>Effective population adjusted by a capacity factor, then times per capita use ____<br>Statistical Analytical Method ____<br>Judgment method based on opinions of DEH/FE personnel ____<br>Other ____<br>(Briefly describe on separate sheet) | Population times per capita use ____<br>Effective population adjusted by a capacity factor, then times per capita use ____<br>Statistical Analytical Method ____<br>Judgment method based on opinions of DEH/FE personnel ____<br>Other ____<br>(Briefly describe on separate sheet) |

12. a. Please place a check next to those potential short-term water shortages for which your installation has prepared written contingency plans:

_______ There are no documented plans at present. (If you checked this answer, please go on to Question 13.)

_______ Drought conditions

_______ Mobilization requirements

_______ Contaminated water quality

_______ Other (Please describe) ________________________________

________________________________________________

b. Which <u>specific</u> water conservation measures are included in the above water shortage contingency plans? Please list each measure separately in the space below:

________________________________________________

________________________________________________

________________________________________________

________________________________________________

________________________________________________

________________________________________________

13. Has your installation implemented a water conservation program within the past 5 years?

Yes__________ No__________ (If you checked NO FOR this answer, please go on to Question 17.)

| QUESTIONS | ANSWERS | | |
|---|---|---|---|
| | Water Conservation Measure #1 | Water Conservation Measure #2 | Water Conservation Measure #3 |
| 14. Please name one specific water conservation measure in each of the boxes which has been used on your installation in the past five years. | | | |
| 15. Briefly describe the reasons for selecting this particular measure. | | | |
| 16. Briefly describe the results of using this conservation measure. | | | |

17. Please fill in the requested information:

| | |
|---|---|
| Your job title ______________ | Point of Contact for follow-up information: |
| Years in this position __________ | Name: ______________________ |
| | Telephone Number ______________<br>(Commercial) |

PLEASE PLACE THIS QUESTIONNAIRE AND A COPY OF THOSE STUDIES WHICH ANALYZE WATER USE FORECASTS OR PATTERNS ON YOUR INSTALLATION IN THE ATTACHED PRE-ADDRESSED STAMPED ENVELOPE AND MAIL WITHOUT DELAY.

THANK YOU FOR YOUR THOUGHTFUL CONSIDERATION TO THE ABOVE QUESTIONS.

# APPENDIX B

## SUMMARY TABULATION OF WATER-RELATED PLANNING INDICATORS

## SUMMARY TABULATION OF WATER-RELATED PLANNING INDICATORS BY MAJOR COMMAND

The following table summarizes the responses obtained from the 1984 Survey of Water Use on Army Installations that pertain to the status of prepared documents or implemented programs concerning water requirement forecasts, water shortage contingency plans and water conservation programs. The table is intended to provide Army planners with an overview of Major Command activities related to water planning on eighty-five installations in the contiguous United States. The presence of a water conservation program indicates that one or more conservation measures have been implemented on an installation within the past five years. The entries represent the number of installations in each category; the numbers in parentheses are corresponding column or row percentages.

| Planning Status | MAJOR COMMAND | | | | | | | | | TOTALS |
|---|---|---|---|---|---|---|---|---|---|---|
| | FORSCOM | TRADOC | DARCOM | USACC | HSC | INSCOM | MTMC | USMA | MDW | N (%) |
| Water Requirement Forecast Only | 1 | 2 | 4 | -- | -- | -- | 1 | -- | -- | 8 (9.4) |
| Water Shortage Contingency Plan Only | 2 | 4 | 4 | -- | -- | -- | -- | -- | 1 | 11 (12.9) |
| Water Conservation Program Only | 7 | 3 | 1 | -- | -- | -- | -- | -- | -- | 11 (12.9) |
| Forecast and Shortage Contingency Plan | -- | 1 | 2 | 1 | -- | -- | -- | -- | -- | 4 (4.7) |
| Forecast and Water Conservation Program | 2 | 2 | 1 | 1 | -- | -- | -- | -- | -- | 6 (7.1) |
| Shortage Contingency Plan and Water Conservation Program | 2 | 1 | 2 | -- | 2 | -- | 2 | 1 | -- | 10 (11.8) |
| All Three Planning Indicators | 3 | 3 | -- | -- | -- | -- | -- | -- | -- | 6 (7.1) |
| None of the Above | 3 | 1 | 19 | -- | 1 | 2 | 1 | -- | 2 | 29 (34.1) |
| TOTALS | 20 (23.5) | 17 (20.0) | 33 (38.8) | 2 (2.4) | 3 (3.5) | 2 (2.4) | 4 (4.7) | 1 (1.2) | 3 (3.5) | 85 (100) |

# APPENDIX C

# INSTALLATION WEATHER-RELATED DATA

## INSTALLATION WEATHER-RELATED DATA

Summer Potential Evapotranspiration ($W_r$) Measured by interpolation of lines of constant summer potential evapotranspiration (Source: contour map, Hittman Associates, Inc., Volume II, 1969).

Summer Rainfall ($r_s$) Measured by interpolation lines of constant summer rainfall (Source: contour map, Hittman Associates, Inc., Volume II, 1969).

Weather Factor ($W_s$ - 0.6) (Source: Howe and Linaweaver, 1967).

| Installation | Latitude | Longitude | $W_r$ | $r_s$ | $W_r - 0.6r_s$ |
|---|---|---|---|---|---|
| Ft. Bragg | 35.02N | 78.54W | 17.4 | 15.6 | 8.04 |
| Ft. Campbell | 36.30N | 87.23W | 19.3 | 10.0 | 13.30 |
| Ft. Carson | 38.49N | 104.48W | 14.0 | 6.5 | 10.10 |
| Ft. Devins | 42.25N | 71.41W | 14.8 | 7.8 | 10.12 |
| Ft. Drumm | 44.00N | 75.55W | 14.2 | 7.0 | 10.00 |
| Ft. Hood | 31.04N | 97.27W | 21.7 | 6.0 | 18.10 |
| Ft. Indiantown Gap | 40.15N | 76.50W | 16.8 | 6.2 | 13.08 |
| Ft. Sam Houston | 29.25N | 98.30W | 21.0 | 6.0 | 17.40 |
| Ft. Lawton | 47.02N | 122.52W | 12.0 | 3.0 | 10.20 |
| Ft. Lewis | 47.14N | 122.17W | 13.1 | 3.0 | 11.30 |
| Ft. McCoy | 43.48N | 91.14W | 15.1 | 9.5 | 9.40 |

## INSTALLATION WEATHER-RELATED DATA (Cont'd)

| Installation | Latitude | Longitude | $W_r$ | $r_s$ | $W_r - 0.6r_s$ |
|---|---|---|---|---|---|
| Ft. McPherson | 33.45N | 84.23W | 16.0 | 13.0 | 8.20 |
| Ft. Meade | 39.20N | 76.38W | 17.0 | 7.0 | 12.80 |
| Ft. Riley | 39.05N | 96.46W | 18.4 | 13.0 | 10.60 |
| Ft. Sheridan | 42.22N | 87.51W | 14.8 | 10.0 | 8.80 |
| Ft. Stewart | 32.04N | 81.07W | 19.0 | 13.0 | 11.20 |
| Ft. Irwin | 34.53N | 117.03W | 18.0 | 0.5 | 17.70 |
| Presidio of San Francisco | 37.45N | 122.26W | 9.5 | 0.5 | 9.20 |
| Vancouver Barracks | 45.31N | 123.41W | 11.6 | 2.4 | 10.16 |
| Yakima Firing Range | 46.35N | 120.30W | 14.0 | 1.4 | 5.60 |
| Ft. Ord | 36.36N | 121.53 | 10.0 | 0.0 | 10.00 |
| Ft. Polk | 31.09N | 93.17W | 20.0 | 13.0 | 12.20 |
| Ft. Belvoir | 38.50N | 77.05W | 18.0 | 8.0 | 13.2 |
| Ft. Benning | 32.29N | 84.56W | 19.2 | 16.0 | 9.60 |
| Ft. Bliss | 31.47N | 106.27W | 20.0 | 4.0 | 17.60 |
| Ft. Chaffee | 35.23N | 94.24W | 19.1 | 9.5 | 13.40 |
| Ft. Dix | 39.40N | 74.50W | 15.9 | 7.3 | 11.52 |
| Ft. Eustis | 37.15N | 76.41W | 16.4 | 11.0 | 9.80 |
| Ft. Gordon | 33.26N | 82.00W | 19.2 | 15.5 | 9.90 |
| Ft. A.P. Hill | 38.20N | 77.30W | 18.0 | 10.0 | 12.00 |
| Ft. Jackson | 34.00N | 81.00W | 17.8 | 15.8 | 8.32 |

INSTALLATION WEATHER-RELATED DATA (Cont'd)

| Installation | Latitude | Longitude | $W_r$ | $r_s$ | $W_r - 0.6r_s$ |
|---|---|---|---|---|---|
| Ft. Knox | 38.15N | 85.45W | 17.1 | 8.8 | 11.82 |
| Ft. Leavenworth | 39.19N | 94.54W | 18.1 | 18.0 | 7.3 |
| Ft. Ben Harrison | 39.45N | 86.08W | 15.8 | 8.0 | 11.00 |
| Ft. Lee | 37.14N | 77.15W | 16.2 | 12.0 | 9.00 |
| Ft. McClellan | 33.39N | 85.47W | 16.0 | 14.5 | 7.30 |
| Ft. Monroe | 36.55N | 76.15W | 16.7 | 13.0 | 8.90 |
| Ft. Hamilton | 40.40N | 73.58W | 16.5 | 6.0 | 12.90 |
| Ft. Pickett | 37.04N | 78.00W | 16.3 | 13.0 | 8.50 |
| Ft. Rucker | 31.28N | 85.28W | 20.1 | 19.0 | 8.70 |
| Ft. Sill | 34.41N | 98.25W | 20.2 | 9.6 | 14.44 |
| Ft. Leonard Wood | 37.56N | 91.45W | 17.7 | 8.7 | 12.48 |
| Carlisle Barracks | 40.10N | 77.15W | 16.9 | 5.0 | 13.90 |
| Ft. Huachuca | 31.30N | 110.25W | 21.0 | 5.0 | 18.00 |
| Ft. Ritchie | 38.05N | 78.50W | 15.0 | 10.0 | 9.00 |
| Anniston AD | 33.39N | 85.47W | 18.9 | 14.5 | 10.20 |
| Army Materials and Mechanics Research Center | 42.15N | 71.07W | 15.1 | 6.0 | 11.5 |
| Harry Diamond Laboratories | 39.00N | 77.00W | 17.0 | 8.0 | 12.20 |
| Letterkenny Army Depot | 40.00N | 77.40W | 16.0 | 7.3 | 11.62 |

INSTALLATION WEATHER-RELATED DATA (Cont'd)

| Installation | Latitude | Longitude | $W_r$ | $r_s$ | $W_r - 0.6r_s$ |
|---|---|---|---|---|---|
| Lexington-Blue Grass | 38.05N | 84.30W | 16.0 | 9.8 | 10.12 |
| McAlester AAP | 34.55N | 95.45W | 20.25 | 9.9 | 14.31 |
| Navajo Depot Activity | 35.15N | 111.40W | 12.0 | 5.0 | 9.00 |
| New Cumberland Army Depot | 40.15N | 76.50W | 17.0 | 6.0 | 13.40 |
| Picatinny Arsenal | 40.54N | 74.30W | 16.3 | 7.5 | 11.80 |
| Pine Bluff Arsenal | 34.13N | 92.01W | 20.0 | 9.4 | 14.36 |
| Pueblo Depot Activity | 38.15N | 104.36W | 15.0 | 6.0 | 11.40 |
| Red River Army Depot | 33.26N | 94.04W | 19.4 | 9.7 | 13.58 |
| Redstone Arsenal | 35.43N | 86.36W | 17.9 | 10.6 | 11.54 |
| Rock Island Arsenal | 41.31N | 90.34W | 16.6 | 11.8 | 9.52 |
| Rocky Mountain Arsenal | 39.44N | 104.59W | 14.3 | 7.3 | 9.92 |
| Sacramento | 38.35N | 121.30W | 15.0 | 0.5 | 14.70 |
| Savanna | 42.05N | 90.09W | 15.3 | 11.6 | 8.34 |
| Seneca | 43.20N | 76.00W | 14.8 | 7.0 | 10.60 |
| Sharpe | 37.56N | 121.16W | 14.0 | 0.5 | 13.70 |
| Sierra | 40.11N | 120.34W | 13.3 | 2.2 | 11.98 |
| Tobyhanna | 41.15N | 75.50W | 15.8 | 7.3 | 11.42 |
| Tooele | 40.33N | 112.17W | 15.6 | 2.8 | 13.92 |
| Umatilla Army Depot | 45.41N | 118.47W | 14.5 | 2.5 | 13.0 |

INSTALLATION WEATHER-RELATED DATA (Cont'd)

| Installation | Latitude | Longitude | $W_r$ | $r_s$ | $W_r - 0.6r_s$ |
|---|---|---|---|---|---|
| Ft. Wingate Depot | 35.30N | 108.45W | 15.5 | 3.4 | 13.46 |
| Watervliet Arsenal | 42.45N | 73.45W | 14.5 | 9.0 | 9.1 |
| Corpus Christi | 27.48N | 97.24W | 21.0 | 9.0 | 15.60 |
| Detroit Arsenal | 42.22N | 83.10W | 14.8 | 10.0 | 8.80 |
| Ft. Monmouth | 40.18N | 73.59W | 17.0 | 7.0 | 12.80 |
| Jefferson Proving Ground | 38.45N | 85.25W | 16.5 | 9.0 | 11.10 |
| St. Louis Area Support Ctr. | 38.42N | 90.09W | 17.6 | 8.0 | 12.80 |
| Aberdeen Proving Ground | 39.20N | 76.38W | 17.0 | 7.0 | 12.80 |
| Dugway Proving Ground | 40.25N | 112.50W | 15.1 | 2.6 | 13.54 |
| Natick Development Center | 42.16N | 71.49W | 14.8 | 8.0 | 10.00 |
| White Sands Missile | 32.50N | 106.20W | 17.5 | 4.0 | 15.10 |
| Yuma Proving Ground | 32.40N | 114.40W | 24.0 | 2.0 | 22.80 |
| Ft. Detrick | 39.25N | 77.25W | 16.5 | 7.0 | 12.30 |
| Fitzsimmons Medical Center | 39.44N | 104.59W | 14.2 | 7.2 | 9.88 |
| Walter Reed Medical Center | 38.50N | 77.00W | 18.0 | 8.0 | 13.20 |
| Arlington Hall Station | 38.55N | 77.10W | 17.5 | 8.0 | 12.70 |
| Vint Hill Farms | 38.45N | 77.50W | 17.5 | 10.0 | 11.50 |
| Bayonne Terminal | 40.44N | 74.10W | 16.0 | 6.0 | 12.40 |

AD-A145 739 FORECASTING WATER USE ON FIXED ARMY INSTALLATIONS
WITHIN THE CONTIGUOUS UNITED STATES(U) ARMY MILITARY
PERSONNEL CENTER ALEXANDRIA VA J F LANGOWSKI 22 JUN 84

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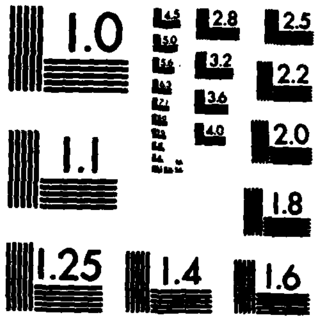


MICROCOPY RESOLUTION TEST CHART
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INSTALLATION WEATHER-RELATED DATA (Cont'd)

| Installation | Latitude | Longitude | $W_r$ | $r_s$ | $W_r - 0.6r_s$ |
|---|---|---|---|---|---|
| Gulf Outport | 30.00N | 90.05W | 19.2 | 14.0 | 10.80 |
| Oakland Army Base | 37.48N | 122.16W | 9.5 | 0.5 | 9.20 |
| Sunny Point Terminal | 34.12N | 77.56W | 17.8 | 31.0 | -0.8 |
| United States Military Academy | 41.12N | 73.58W | 16.0 | 7.0 | 11.80 |

# APPENDIX D

## COMPARISON OF ESTIMATION RESULTS BY INSTALLATION

# APPENDIX D

## COMPARISON OF ESTIMATION RESULTS BY INSTALLATION

The following table presents the reported actual values for average daily water service ($Q_{Actual}$) obtained by dividing entries of total annual water service (FY 1981 Redbook) by 365 days. Estimated values ($Q_{Est}$) are shown for average daily water service computed by applying both current Army procedures (Chapter 4) and the water requirement model developed in Chapter 5. Residuals are displayed for both techniques.

| | FY 81 Redbook | Current Procedures | | Water Requirement Model | |
|---|---|---|---|---|---|
| Installation | $Q_{Actual}$ | $Q_{Est}$ | Residual | $Q_{Est}$ | Residual |
| Ft. Bragg | 6477 | 6437 | 40 | 6891 | -414 |
| Ft. Campbell | 4991 | 6515 | -1524 | 4919 | 73 |
| Ft. Carson | 3321 | 6254 | -2933 | 3153 | 167 |
| Ft. Devins | 1575 | 4661 | -3086 | 3104 | -1530 |
| Ft. Drum | 447 | 945 | -498 | 1633 | -1216 |
| Ft. Hood | 7959 | 9960 | -2001 | 6813 | 1146 |
| Ft. Indiantown Gap | 642 | 1252 | -610 | 1769 | -1127 |
| Ft. Sam Houston | 3790 | 4203 | -413 | 3099 | 690 |
| Ft. Lawton | 65 | 33 | 32 | 145 | -81 |
| Ft. Lewis | 7288 | 6576 | 712 | 5954 | 1334 |
| Ft. McCoy | 596 | 5861 | -5265 | 2461 | -1865 |
| Ft. McPherson | 1025 | 2214 | -1189 | 1791 | -766 |

APPENDIX D (cont'd)

| Installation | FY 81 Redbook | Current Procedures | | Water Requirement Model | |
|---|---|---|---|---|---|
| | $Q_{Actual}$ | $Q_{Est}$ | Residual | $Q_{Est}$ | Residual |
| Ft. Meade | 3135 | 6893 | -3758 | 3374 | -239 |
| Ft. Riley | 4134 | 5927 | -1793 | 4436 | -302 |
| Ft. Sheridan | 645 | 1390 | -745 | 1374 | -729 |
| Ft. Stewart | 3412 | 6511 | -3099 | 3441 | -30 |
| Ft. Irwin | 1031 | 1179 | -148 | 655 | 376 |
| Presidio of San Francisco | 3584 | 2779 | 805 | 2584 | 1000 |
| Vancouver Barracks | 135 | 12 | 123 | 191 | -55 |
| Yakima Firing Range | 473 | 73 | 400 | 191 | 283 |
| Ft. Ord | 6135 | 6213 | -78 | 5450 | 685 |
| Ft. Polk | 3796 | 5508 | -1712 | 4166 | -370 |
| Ft. Belvoir | 1805 | 3077 | -1272 | 3186 | -1380 |
| Ft. Benning | 6774 | 6552 | 222 | 6176 | 598 |
| Ft. Bliss | 5982 | 6389 | -407 | 5107 | 875 |
| Ft. Chaffee | 693 | 1579 | -886 | 1228 | -535 |
| Ft. Dix | 2901 | 4361 | -1460 | 3266 | -365 |
| Ft. Eustis | 2857 | 2423 | 434 | 2034 | 823 |
| Ft. Gordon | 2258 | 4375 | -2117 | 2927 | -669 |
| Ft. A.P. Hill | 97 | 276 | -179 | 501 | -404 |
| Ft. Jackson | 4567 | 4204 | 363 | 3312 | 1255 |
| Ft. Knox | 5090 | 6635 | -1545 | 6286 | -1196 |

APPENDIX D (cont'd)

| Installation | FY 81 Redbook | Current Procedures | | Water Requirement Model | |
|---|---|---|---|---|---|
| | $Q_{Actual}$ | $Q_{Est}$ | Residual | $Q_{Est}$ | Residual |
| Ft. Leavenworth | 2055 | 2070 | -15 | 2144 | -90 |
| Ft. Benjamin Harrison | 552 | 2656 | -2104 | 1554 | -1001 |
| Ft. Lee | 1655 | 2878 | -1223 | 2335 | -679 |
| Ft. McClellan | 1507 | 3308 | -1801 | 1881 | -373 |
| Ft. Monroe | 1510 | 729 | 781 | 613 | 897 |
| Ft. Hamilton | 449 | 2431 | -1982 | 989 | -540 |
| Ft. Pickett | 720 | 517 | 203 | 810 | -90 |
| Ft. Rucker | 2488 | 3887 | -1399 | 2306 | 182 |
| Ft. Sill | 3049 | 4767 | -1718 | 4117 | -1068 |
| Ft. Leonard Wood | 4010 | 4799 | -789 | 3932 | 79 |
| Carlisle Barracks | 607 | 543 | 64 | 488 | 119 |
| Ft. Huachuca | 2680 | 2820 | -40 | 2365 | 315 |
| Ft. Ritchie | 439 | 1269 | -830 | 581 | -142 |
| Anniston Army Depot | 1262 | 1072 | 190 | 756 | 506 |
| Army Materials and Mechanics Research Center | 65 | 165 | -100 | 380 | -315 |
| Harry Diamond Laboratories | 88 | 311 | -223 | 456 | -367 |
| Letterkenny Army Depot | 566 | 1254 | -688 | 711 | -151 |
| Lexington Blue-Grass AD | 247 | 431 | -184 | 542 | -294 |
| McAlester AAP | 568 | 243 | 325 | 888 | -319 |
| Navajo Depot Activity | 82 | 55 | 27 | 299 | -216 |

APPENDIX D (cont'd)

| Installation | FY 81 Redbook | Current Procedures | | Water Requirement Model | |
|---|---|---|---|---|---|
| | $Q_{Actual}$ | $Q_{Est}$ | Residual | $Q_{Est}$ | Residual |
| New Cumberland Army Depot | 342 | 1509 | -1167 | 661 | -319 |
| Picatinny Arsenal | 2544 | 1230 | 1314 | 1532 | 1013 |
| Pine Bluff Arsenal | 863 | 312 | 551 | 321 | 543 |
| Pueblo Depot Activity | 241 | 203 | 38 | 560 | -319 |
| Red River Army Depot | 1404 | 1305 | 99 | 747 | 656 |
| Redstone Arsenal | 9847 | (Outlier) | | (Outlier) | |
| Rock Island Arsenal | 1323 | 1629 | -306 | 992 | 332 |
| Rocky Mountain Arsenal | 188 | 86 | 102 | 250 | -62 |
| Sacramento Army Depot | 502 | 666 | -164 | 345 | 157 |
| Savanna Army Depot | 219 | 146 | 73 | 405 | -186 |
| Seneca Army Depot | 252 | 380 | -128 | 518 | -265 |
| Sharpe Army Depot | 225 | 366 | -141 | 317 | -92 |
| Sierra Army Depot | 1123 | 347 | 776 | 537 | 586 |
| Tobyhanna Army Depot | 388 | 936 | -548 | 499 | -111 |
| Tooele Army Depot | 30 | 962 | -932 | 742 | -711 |
| Umatilla Depot Activities | 167 | 73 | 94 | 259 | -92 |
| Ft. Wingate Depot Activity | 12 | 44 | -32 | 108 | -96 |
| Watervliet Arsenal | 317 | 652 | -335 | 428 | -110 |
| Corpus Christi Army Depot | 717 | 714 | 3 | 216 | 501 |

APPENDIX D (cont'd)

| Installation | FY 81 Redbook | Current Procedures | | Water Requirement Model | |
|---|---|---|---|---|---|
| | $Q_{Actual}$ | $Q_{Est}$ | Residual | $Q_{Est}$ | Residual |
| Detroit Arsenal | 495 | 1270 | -775 | 550 | -55 |
| Ft. Monmouth | 764 | 2050 | -1286 | 1933 | -1168 |
| Jefferson Proving Ground | 47 | 106 | -59 | 160 | -113 |
| St. Louis Area Support Center | 179 | 226 | -47 | 329 | -150 |
| Aberdeen Proving Ground | 3848 | 5501 | -1653 | 4203 | -355 |
| Dugway Proving Ground | 1188 | 602 | 586 | 640 | 548 |
| Natick Development Center | 2827 | 365 | 2462 | 527 | 2300 |
| White Sands Missile Range | 1947 | 1748 | 199 | 2392 | -455 |
| Yuma Proving Ground | 900 | 648 | 252 | 507 | 393 |
| Ft. Detrick | 1594 | 931 | 663 | 694 | 900 |
| Fitzsimmons Army Medical Center | 850 | 1001 | -151 | 863 | -13 |
| Walter Reed Army Medical Center | 1300 | 1814 | -514 | 2257 | -956 |
| Arlington Hall Station | 157 | 632 | -475 | 296 | -139 |
| Vint Hill Farms | 232 | 465 | -233 | 357 | -126 |
| Bayonne Military Ocean Terminal | 417 | 682 | -265 | 787 | -370 |
| Gulf Outport | 17 | 54 | -37 | 89 | -72 |
| Oakland Army Base | 326 | 637 | -311 | 481 | -154 |
| Sunny Point Military Ocean Terminal | 101 | 70 | 31 | 31 | 70 |
| United States Military Academy | 2975 | 2709 | 266 | 3476 | -502 |

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